Post Occupancy Review of Comfort Conditions at Heelis, Central Office Building for the National Trust

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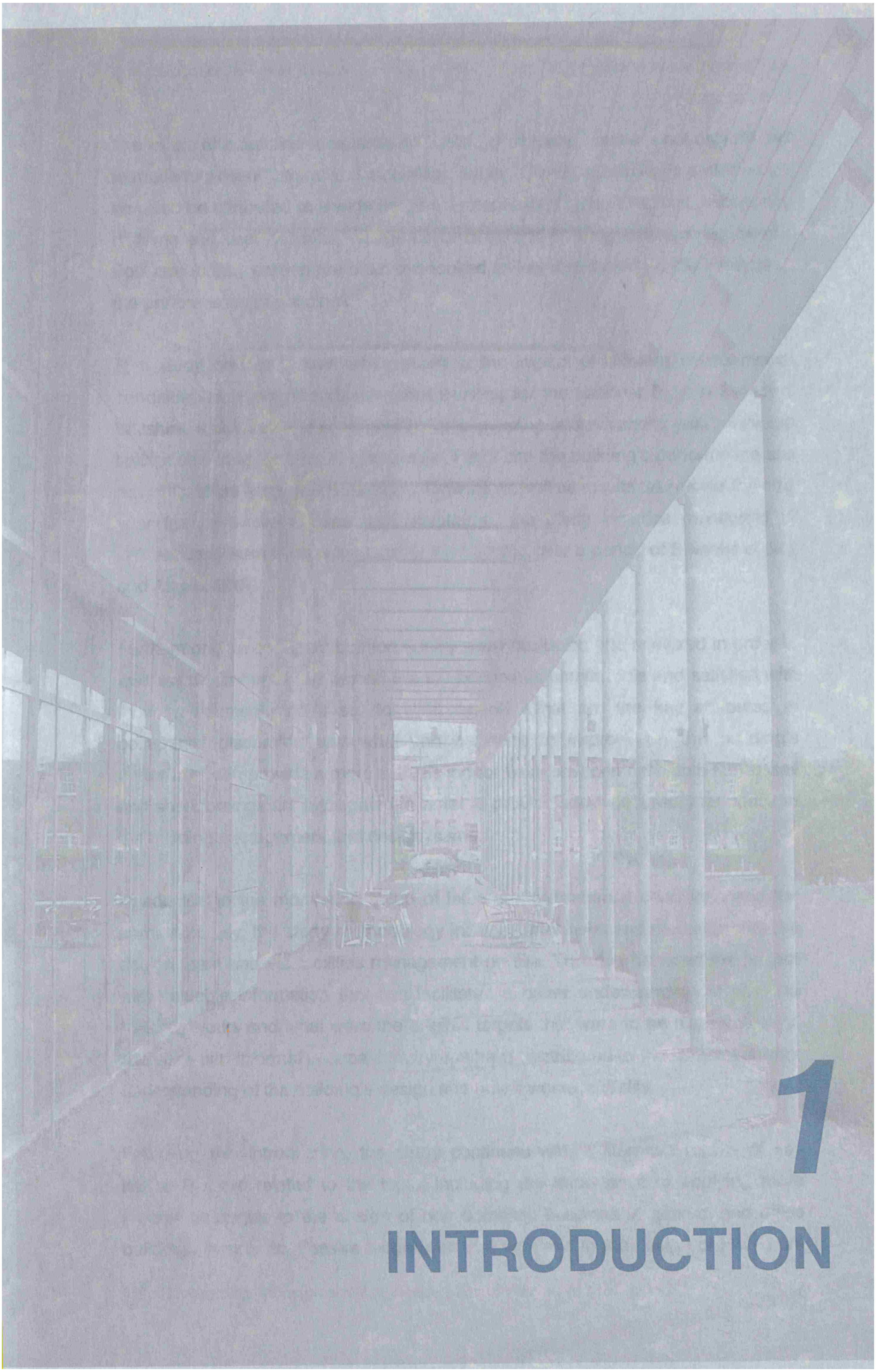
Abstract

The environmental impact of buildings is not fully realized during the design stage, of its life cycle, where it is usually quite difficult to foresee how well it would perform under various conditions. At a time when more energy efficient and passive solutions to the design of the built environment are paramount, it is becoming more essential to bridge the credibility gap between design targets and actual building performance, particularly during its post occupancy stage [1].

This study examines comfort conditions at Heelis, the Central Office Building for the National Trust in Swindon, Wiltshire. The research follows on after a series of reviews and studies that were conducted last year. Building visits, an occupant comfort survey and physical monitoring are used to obtain data on indoor air temperature, radiant temperature, relative humidity, air velocity, and daylight factors. In addition, the questionnaire survey is used to examine occupants' comfort and satisfaction with their indoor environment in different zones of the building and the results are compared to data from the calculated dry resultant temperature.

This study shows that for the monitored period during the summer of this year, overall conditions were satisfactory as proven by resultant temperatures between 20 and 24°C. Although no overheating occurred this year, the relationship between air and radiant temperatures is used to predict resultant temperature for 2006, an exceptionally hot summer. This has shown that although air temperatures do not exceed design benchmarks, resultant data shows some overheating on the first floor of the building where resultant exceeds 28°C for 3.4% of working hours.

Daylight factors are also found to be up to 50% less than predicted values in some parts of the building. The monitoring and analysis has shown that although the building is performing rather well, some areas are in need of some improvement, emphasizing the importance of post occupancy evaluation in general in improving building performance and bridging the gap between design targets and performance data.



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INTRODUCTION

The failure of a building to achieve its 'as designed' performance is not only related to modelling assumptions and modelling 'errors'. Clearly, a building's performance can also be attributed to a wide range of factors including building use, occupancy patterns and user behavior, design constraints, and building management needs. Post occupancy studies are often overlooked as key drivers behind the success of the performance of buildings.

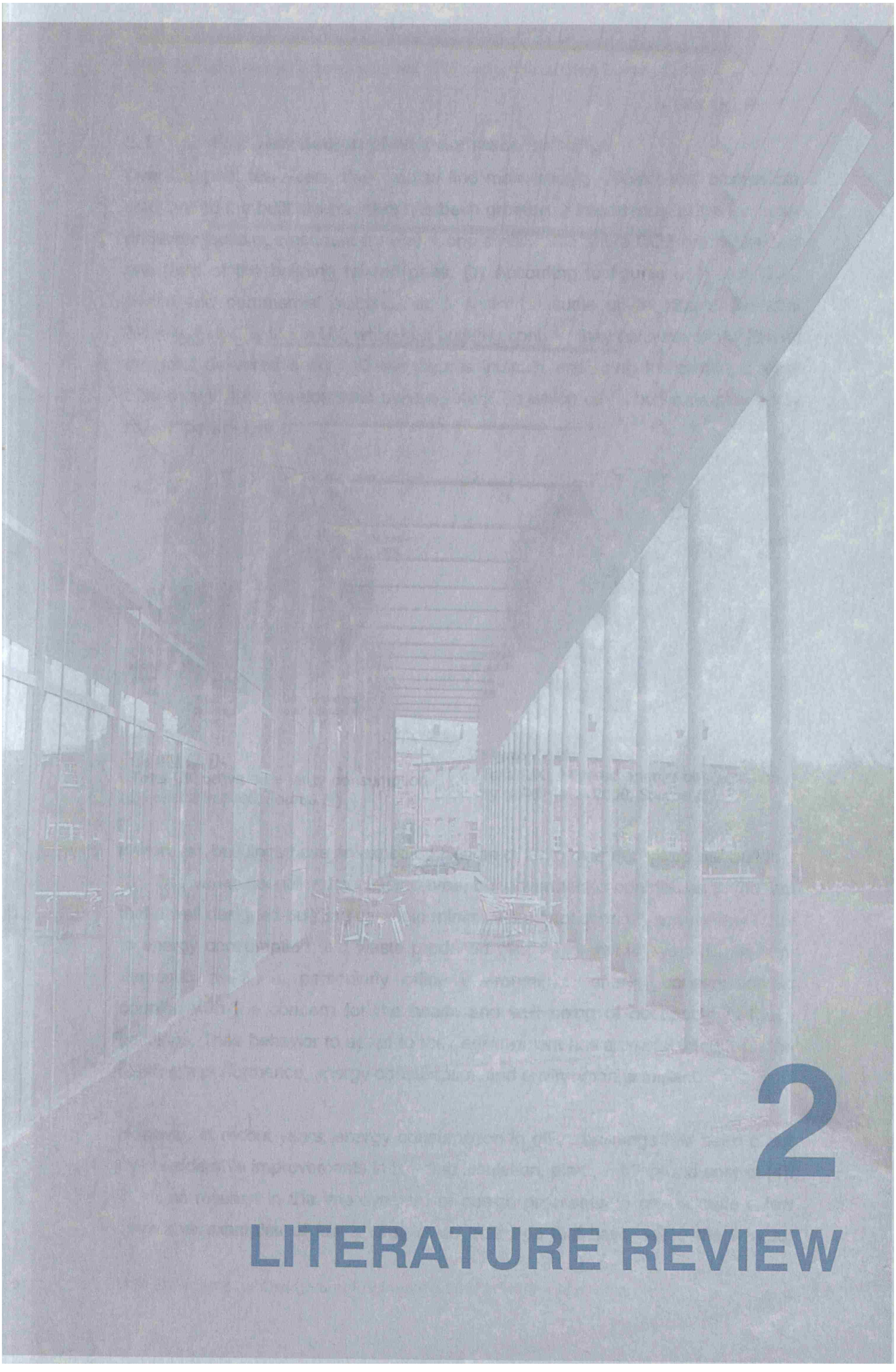
This study concerns itself with examining the impact of different environmental conditions at Heelis, the central office building for the National Trust in Swindon, Wiltshire, a building that is notable for its pioneering and advanced passive design techniques. In an attempt to gain some insight into the building's performance and how this differs from original design intentions as well as results taken over the past year from previous reviews and monitoring, the study includes monitoring of internal conditions in different parts of the building over a period of 5 weeks in July and August 2007.

Furthermore, an occupant comfort survey was conducted and analyzed in order to address a number of key issues: are the occupants comfortable and satisfied with their environment and if so, to what extent? What are the key attributes to occupants' discomfort and what can be done to improve on the building's performance to provide a more suitable indoor work environment? Both successes and shortcomings are highlighted in order to provide some necessary feedback to the building management and design teams.

In addition to the monitoring setup of internal environmental conditions and the comfort survey, the study methodology includes interviews and meetings with the design team and the facilities management on site. This has provided the project with valuable information that has facilitated a better understanding of how the building works and what were the original targets that were to be met. Moreover, site visits and informal occupant interviews have contributed to the author's deeper understanding of the building's design and how it works in reality.

Following this introduction, the study continues with a literature review of key issues that are related to the topic, including the importance of applying more passive strategies to the design of non domestic buildings in general and office buildings in specific. Passive techniques that are used in the design of Heelis are then explained in further detail. Following from there is a description of post occupancy evaluation of non domestic buildings: its key concepts, evolution and development over the past few years.

A comprehensive description of the building and its main strategies follows in chapter 4, which also includes a review of the building's performance last year based on previously published reports. Chapter 5 then includes the results and analysis for both the occupant comfort survey and environmental conditions analysis for this year. The results are discussed and evaluated further in chapter 6 with the main conclusions and suggestions for future work then found in the final chapter.



2

LITERATURE REVIEW

2.1 Sustainable design of non-domestic buildings

Over the past few years, the need to find more energy efficient and sustainable solutions to the built environment has been growing in importance. In the UK, non-domestic buildings account for about one sixth of the entire CO2 emissions and one third of the building related ones. [1] According to figures (2.1) and (2.2), public and commercial buildings as a sector consume up to 13% of the total delivered energy in the UK, while in a building context, they consume up to 28% of the total delivered energy. These figures indicate one thing for certain; energy efficiency in the non-domestic building stock, in which office buildings play a key role, is paramount.

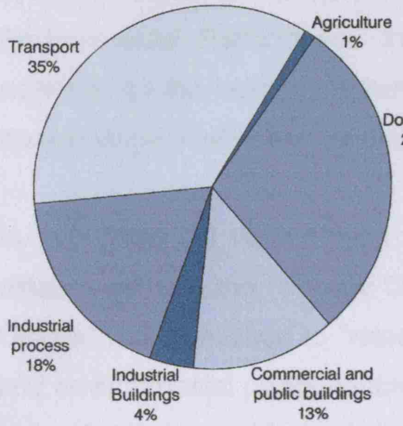


Figure (2.1):
Total UK delivered energy consumption by sector in 2000, *Source [2]*

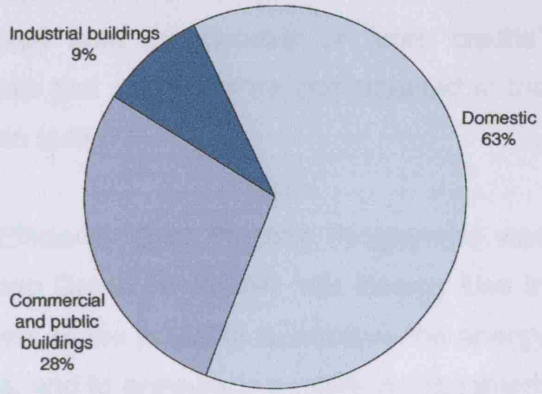


Figure (2.2):
Total UK delivered energy consumption by buildings in 2000, *Source [2]*

In general, buildings have an expected lifetime of 20 to over 100 years per building [3]. This varies according to building type, but nevertheless contributes to the fact that a well designed building can help minimize the impact on the environment due to energy consumption and waste produced over its overall lifecycle [8]. In non-domestic buildings, particularly office environments, energy conservation is coupled with the concern for the health and well being of occupants of these buildings. Their behavior to adapt to their environment has a crucial impact on the building's performance, energy consumption and environmental impact.

However, in recent years, energy consumption in office buildings has been offset by considerable improvements in building insulation, plant, lighting and control [4]. This has resulted in the improvement of design processes to create quite a few innovative examples of low energy office buildings that have paved the way for further developments in the field of low energy design. Some of the most important tools that have facilitated this include approved building assessment methods for non-domestic buildings and amendments or developments in the building regulations, both of which helped in creating benchmarks that designers can aim to achieve in order for them to create more efficient buildings.

Launched in 1990, the Building Research Establishment Environmental Assessment Method (BREEAM) set out to provide guidelines on ways to minimize the impact of buildings on the global and local environments while promoting healthy and comfortable indoor environments for users [6]. According to the BREEAM 2005 for offices, buildings are awarded ratings which include an Environmental Performance Index derived from the number of "core credits" achieved by the buildings which are issues that can either be implemented at the design stage or after the building has been built [7].

In 2000, the UK Government Energy Efficiency Best Practice Programme was established and the "Energy Consumption Guide 19 (ECON 19): Energy Use in Offices" was published to "raise awareness of the potential to improve the energy and environmental performance of offices, and to encourage positive management action." [4] It provides information and sets benchmarks* that are applied to buildings as a whole, in addition to environmental services and their components. In order to ensure that necessary consideration is given to various environmental issues, it is recommended that an overall environmental policy is adopted, accompanied by an environmental management system to implement it. Although the most important decisions that affect a building's impact are taken in early stages of its design, it is important to consider that later stages of occupation and feedback are crucial to its environmental management [5].

* Building energy benchmarks provide" representative values for common building types, against which one can compare a building's actual performance" While simple benchmarks for annual energy use per square meter of floor area would permit for the assessment of the standard of energy efficiency, more detailed benchmarks are used to pinpoint problem areas within a building [ ].

2.2 Passive Design Strategies

2.2.1 Introduction

In order for passive or low energy design strategies to be effective, they must consider the building and its service systems holistically [9]. In addition to the obvious benefits of using more passive strategies in the design of office buildings with regards to reducing energy consumption and subsequent CO2 emissions, there are a number of other benefits to be considered. Studies have shown that productivity levels in low energy commercial buildings tend to be higher [10], which is attributed to the fact that many low energy buildings increase occupant motivation and well being by including key design features like daylight, natural ventilation and planted atria and courtyards.

Furthermore, maintenance costs are usually lower in low energy buildings as there will most likely be less energy consuming plant installed that is run for fewer hours during the heating season [9]. Table (2.1) shows the role various aspects of the built environment play in energy consumption. Understanding how these factors contribute to a building's energy performance would allow for reducing energy consumption to minimal levels whilst maintaining comfort standards and a high quality indoor environment. These factors have varying relevance depending on the building type and its services. Generally however, the emphasis on low energy strategies is driven by knowledge of predicted energy flows within the built environment and how those change throughout the different stages of a building's life cycle [9].

Design variable	Role and impact on low energy design
Site and climate	Energy is used to create a more temperate climate when external conditions are severe (too hot or too cold). The more extreme external conditions are, the more energy is consumed to create comfortable internal conditions. Landscaping is a good way to create a comfortable microclimate in which a building can be situated.
Building form	Building form dictates the size of the surface area and volume. These in turn, are directly proportional to the fabric and ventilation heat loss rates respectively. Building form also determines the ability with which natural energy like solar heat, light and natural ventilation can be collected and used.
Building fabric	The heat transfer characteristics of the external envelope determine fabric heat loss rates. Low density materials and insulators can be used to slow the passage of heat while dense, thermally massive materials can be used internally to help cool a building in summer (see section 2.2.2)
Building ventilation	Because of the negative effect of uncontrolled infiltration through the building fabric, efforts should be exerted to minimize it. Furthermore, mechanical ventilation systems consume electricity and should be operated more efficiently and only when necessary.
Daylighting	Natural light can be used to displace the use of artificial lighting. Glazed openings in a building's external envelope have a large effect on this where a balance must be achieved using shading devices that would minimize direct solar gains without obstructing too much daylight when it is needed.
Artificial lighting	Lighting can consume up to 20% and 16% of total energy consumption in naturally ventilated and air conditioned offices respectively. It should therefore be produced efficiently with correct control mechanisms and only when required.
Passive solar heating	It can be used to displace the use of mechanical heating created from the burning of fossil fuels. However, it requires well planned control systems that allow for the full advantage to be made from natural energy flows.
Heating systems	Space heating can consume up to 60% and 48% of total energy consumption in naturally ventilated and air conditioned offices respectively. They should therefore be used only when necessary and again, with appropriate levels of control and should be maintained regularly
Cooling	In order to conserve energy consumption that results from cooling, passive methods should be used as a first option; These include shading devices and exposed thermal mass couple with night time cooling. Only when passive cooling is inadequate, mechanical systems should be chosen and operated efficiently as required only.
General services	Efficient systems to operate lifts, escalators, emergency lighting and other systems should be chosen and used as required only as they consume large amounts of electricity (up to approximately 12% in naturally ventilated offices).
Post occupancy energy management	The loss of adjustment in controls can cause energy consuming equipment to operate inefficiently. It is important that building energy consumption is monitored and managed after its occupancy in order to ensure that its remains on target.

Table (2.1):
Factors and variables that contribute to energy consumption in building and the role they play in its energy performance, *Source [9]*

2.2.2 Thermal mass

Usually a dense material that is part of the building structure or envelope, thermal mass absorbs or releases heat from or to interior spaces [11]. Thermal mass, coupled with night time cooling is one of the most effective passive design strategies that can be used in naturally ventilated buildings. Its effectiveness depends on a number of factors including the specific heat capacity of materials used, the position of the thermal mass itself within the building as well as the use of other lightweight and finishing materials that might have decrease its effectiveness. Despite the preconceived notion that it is a simple, cost effective method for achieving comfort conditions, its efficiency is much more complex and depends on a number of factors shown in table (2.2) below.

Factor	Effect on thermal mass
Material thermal properties and performance	Materials must have a proper density, high thermal capacity and high thermal conductivity
Location and distribution	Direct locations with direct solar heat gains are more effective for heat storage mass than indirect locations. In northern orientations, there is little need for time lag as they exhibit small heat gains in general. In eastern orientation, either a very long time lag of >14 hours or a very short one, where the latter is recommended as long time lags are economically unfeasible. In south orientation, an 8 hour time lag is sufficient to delay the heat from midday to evening hours. The same applies for western orientations where 8 hours would also be sufficient as there are a few hours only until sunset.
Insulation	Although important in buildings where a lot of heating is required, thermal insulation can degrade the performance of thermal storage walls in climates where cooling is required. Overall, because thermal mass stores and releases heat, it interacts with the building operation more than just by adding insulation, making it more difficult to treat
Role of ventilation	Night time ventilation plays an essential role in using thermal mass for the passive cooling of buildings (see below) Proper ventilation controls are essential in order to ensure the proper operation of night time cooling and subsequent efficiency of thermal mass
Occupancy patterns	When the building is occupied and for how long is also important as it affects the time for which thermal mass is required to create a lag for the release of heat into the internal spaces.

Table (2.2): Factors that affect the efficiency of thermal mass in buildings, *Source [11]*

In office buildings, the external envelope plays a number of roles in modifying the internal climate of a building including the preservation of stable and comfortable internal surface temperatures throughout the occupation period under both summer and winter conditions. It has been found that locating thermal insulation outside a dense element provides excellent climate modification simultaneously with excellent thermal inertia for the internal environment and is hence a preferred option as it provides warmth in winter and cool conditions in summer [10] (see also table (2.2) above).

The effect of thermal mass on heating and cooling of buildings can be seen in figures (2.3) and (2.4). Figure (2.3) shows the effect of the input of solar gain to both a lightweight and a heavyweight building that can be used for passive heating in both cases in winter.

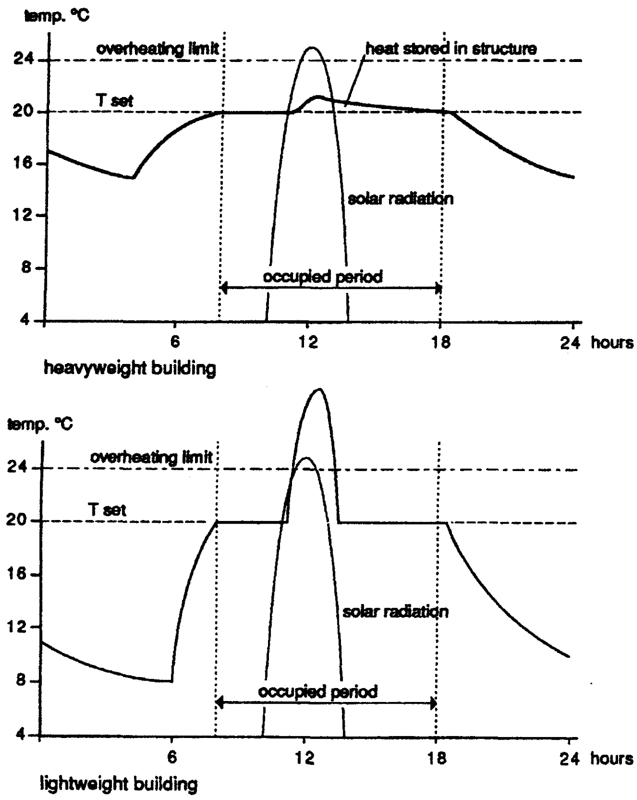


Figure (2.3):
The effect of solar gains on heavy and lightweight buildings:

Overheating occurs quickly in the lightweight case, requiring the rejection of heat to achieve comfort through shading, ventilation or even mechanical cooling. Because of the "massive" construction material used in the heavyweight building, it is able to absorb the sudden gain, where the stored energy helps delay the demand for heating as external temperatures drop. It maintains a higher internal temperature overnight, thereby reducing the energy required to pre-heat the space the following morning, *Source [10]*

In summer, heat is stored in thermal mass structure, thus reducing the cooling loads peaks. A reduced portion of the load will need to be removed from the interior space while the remaining part of the external and internal heat gains is contained within the thermal storage materials. The stored heat is progressively released to the interior of the building at a later time [10].

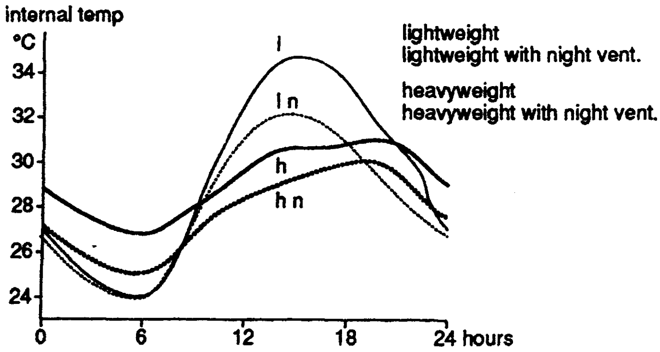


Figure (2.4):
Response of different heavy and lightweight buildings to night ventilation from computer simulations:

Night cooling is coupled with thermal mass to provide high ventilation rates at night that would selectively drive the internal temperature to reach that of the outside in order for the average temperature in the building overall to be below the average ambient. This is particularly useful in hot climates where large diurnal ranges exist and night temperatures are much cooler and can be used to reduce the temperature of the interior of buildings. According to the figure, for diurnal temperature variation as little as 8°C, night ventilation combined with a heavyweight building can be beneficial to daytime conditions, lowering temperatures by about 3°C, *Source [10]*

There are a number of key issues one needs to address through different stages of the building's life cycle in order to ensure that the application of this passive strategy can produce optimum results. These issues relate to solutions concerning the mass structure itself, integration issues, control, acoustics, HVAC strategies, lighting and evaluation. Figures (2.5) and (2.6) show the key design development and operational issues respectively.

These issues need to be checked when incorporating thermal mass through either a flat or contoured exposed structural ceiling/floor slab within the design. They are drawn from a review of recent buildings adopting the strategy† [12].These figures show that approaching low energy design from a life cycle approach has an effect

† Further details of some of the issues can be found in Barnard N, Concannon P and Jaunzens D, *Modelling the Performance of Thermal Mass, BRE Information Paper IP 6/01*, Garston, Construction Research Communications Ltd, 2001

on design details such as the choice of design strategy and its application within the building environment. The issues that designers need to address involve how well it would be integrated into the overall building "system". This highlights further issues related to occupants' interaction with their environment through control and is therefore a mere reminder of the importance of following up on design decisions beyond the project handover.

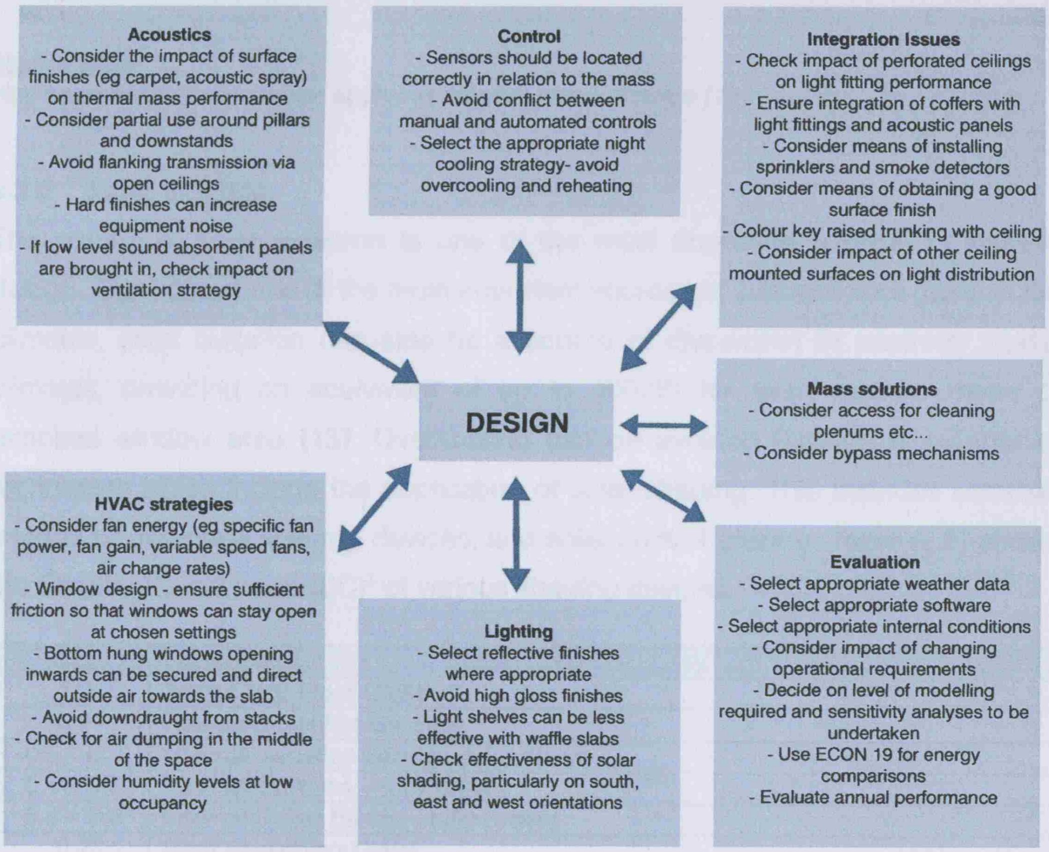


Figure (2.5):
Key design development issues when applying thermal mass, *Source [12]*

Figure (2.6):
Key operational issues when applying thermal mass, *Source [12]*

2.2.3 Solar shading

The control of solar radiation is one of the most important aspects of passive design. Considered one of the most important sources of summer heat gains in hot climates, solar radiation can also be a source of discomfort in relatively colder climates, providing an equivalent of up to 1000W for every square meter of exposed window area [13]. Overheating can be avoided through a number of techniques which include the application of solar shading. This includes external, internal or mid-pane shading devices, and solar control glazing. Table (2.3) shows the Shading Coefficients (SC)‡ of various shading devices.

SC	Description
1.0	3mm Clear Float Glass
0.9	Standard Double Glazing
0.5 – 0.9	Internal Venetian Blinds – fully drawn
0.4 – 0.8	Internal Curtains – fully drawn
0.4 – 0.8	Internal Roller Blinds – fully drawn
0.7	Heat Absorbing Glass
0.6	Vegetation and trees providing light shade
0.5	Internal Blind with Reflective Foil Backing
0.4	Solar Control Glass
0.3	1m Eaves Overhang on Equator-Facing Side
0.2	2m Pergola on Equator-Facing Side
0.2	External Blinds - Fully Drawn
0.2	External Shutters - Fully Drawn

Table (2.3):
A comparison of shading coefficients for different types of shading devices, *Source [13]*

‡ The Solar Coefficient (SC) is the fraction of solar radiation transmitted by the specified device, compared to that transmitted by an unprotected sheet of 3mm clear float. The lower the SC, the less solar heat passes through, thus the more effective the device [13].

Generally, solar shading can be seen as a highly cost effective way of controlling overheating that can be incorporated into the design to give optimum results with a relatively small payback period of less than 5 years [14]. A recent BRE study published in 2000[§] estimates that installing air conditioning in a typical 60's open plan office would require an extra 55 kWh/m² per year, resulting in an overall running cost for the air conditioning of £15 per m² per year. The same study shows that comfort could be achieved at zero cooling energy consumption with a combination of solar shading and night time ventilation. The extra costs of applying these passive measures will usually be substantially less than that of installing air conditioning in the office, notwithstanding any additional costs due to maintenance of the system itself [14].

Table (2.4) outlines the performance data for several shading systems that can be used in non domestic buildings in general. Of all the systems mentioned in the table, sophisticated external louver systems are the only ones that are really effective at controlling solar gain and glare simultaneously. Nevertheless, a hybrid system can be adopted for optimum results, where an overhang can be used to control heat gains for example while internal blinds can be applied to control glare.

When deciding the choice and position of the shading device, the designer must consider a wide range of issues that include among other factors: the amount of control required over the devices themselves as well as the degree to which they will affect natural lighting and the overall ventilation strategy [13]. This highlights the importance of integrating solar shading into an overall approach to passive design that is applied to the building. Furthermore, in the design of new buildings, it is important to consider solar shading at early design stages as it becomes increasingly difficult or costly to install shading systems well into later stages of the building's life cycle [15].

§ Building Research Establishment (BRE) study, Comfort Without Air Conditioning in Refurbished Offices: An Assessment of Possibilities, New Practice Case Study NPCS118, The Carbon Trust, 2000, available from www.carbontrust.co.uk

System	Best For	Relative total solar transmittance		Relative daylight transmittance		Adjustability	Privacy	Glare Control
		Summer	Winter	Diffuse	Back of room			
Clear double glazing, no shading		1	1	1	1	○	○	○
Overhangs	S	0.55	0.84	0.61	0.72	●	○	●●
Light shelves	S	0.51	0.78	0.52	0.90	●	○	●●
External louvre Shut	H	0.04	0.04	0.03	0.03	●*	●●●	●●**
External louvre Open	H	0.26	0.45	0.32	0.50			
Tinted glazing	SEWH	0.71	0.68	0.49	0.49	○	●●	●
Heat mirror glazing	SEWH	0.66	0.63	0.79	0.79	○	●	○
Window film	SEWH	0.51	0.49	0.33	0.33	○	●●	●
Reduced window area	Any	0.50	0.50	0.50	0.50	○	●	○
Mid pane venetian Shut	NSEW	0.43	0.43	0.03	0.03	●●*	●●●●	
Mid pane venetian Open	NSEW			0.32	0.50			
Fixed mid pane louvres	H	0.37	0.90	0.60	0.68	●	●●●	●●
Curtains	Any	0.50	0.49	0.06	0.06	●●●	●●●	●●●**
Venetian blind Shut	Any	0.57	0.58	0.03	0.03	●●●	●●●	●●●·
Venetian blind Open				0.32	0.50			
Roller blind	Any	0.43	0.43	0.06	0.06	●●●	●●●	●●●**
Reflective roller blind	Any	0.34	0.33	0.04	0.04	●●●	●●	●*

Key:

Window types: N = north, E = east, W = west, H = horizontal

Adjustability: ○ = Performance doest not vary significantly, ● = seasonal variation in performance, ●● = some user adjustability, ●●● = completely adjustable, * = some types completely adjustable

Privacy: ○ = no improvement in privacy, ● = some improvement in privacy, ●● = good privacy by day but not at night, ●●● = good privacy all the time

Glare control: ○ = no improvement in glare, ● = reduces sky glare but does not eliminate sun glare, ●● = reduces sky glare and eliminates sun glare at certain times, ●●● = eliminates sky and sun glare, * = opaque types eliminate sky and sun glare, ** = some types do not eliminate sun glare

Table (2.4): Summary of performance data for different shading systems, *Source [15]*

2.3 Thermal comfort and user control in office buildings

Modern control and energy management systems offer the potential to maintain comfort levels for building occupants whilst reducing energy consumption [16]. Environmental conditions that define comfort in buildings involve various parameters over which occupants can have control with varying degrees. These include lighting, ventilation, heating and cooling. Generally, occupants are more critical of conditions that they have little or no control over [16]. This is why fully automatic control systems may not be the complete answer in most cases [16]. A research report published by the BRE shows that studies of building related ill-health reveal fewer symptoms and greater productivity levels in office environments as the perceived level of individual control increases, which can be seen in figure (2.8) [16].

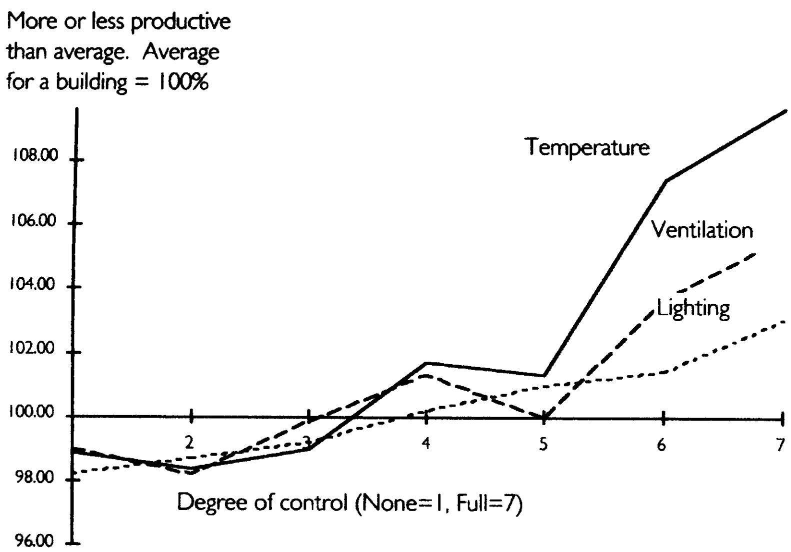


Figure (2.8):
Productivity versus degree of control, *Source [16]*

Although important to building performance and human comfort, the ways in which controls are perceived and used by occupants have not been thoroughly researched and if so, only incidentally [17]. Some literature adopts the holistic approach where the context in which controls are used, the interactions between simultaneously operating ones and the requirements of user interfaces are examined together. This approach acknowledges that users in general would want to alter the targets that controls are set to achieve. Therefore, systems should keep "the measured variables within suitable tolerances, but also be able to respond effectively when, for one reason or other; the set parameters become regarded as unsatisfactory" [17].

Bordass, Leaman and Willis [17] summarized the essential areas in which control systems aim to maximize comfort with minimum energy use as shown in the strategic diagram in figure (2.9). According to the figure, controls can either be manual or automatic (represented by the vertical axis) and reactive or forward looking (horizontal axis). This classification results in four main areas: feedback, feedforward, intervention and anticipation, where "a satisfactory control strategy should consider relevant issues in each field, in addition to interactions between them. For example, a feedback device (quadrant A) will usually need programming or setting (quadrant B), requiring manual intervention either at the time (quadrant C) or beforehand (quadrant D)" [17].

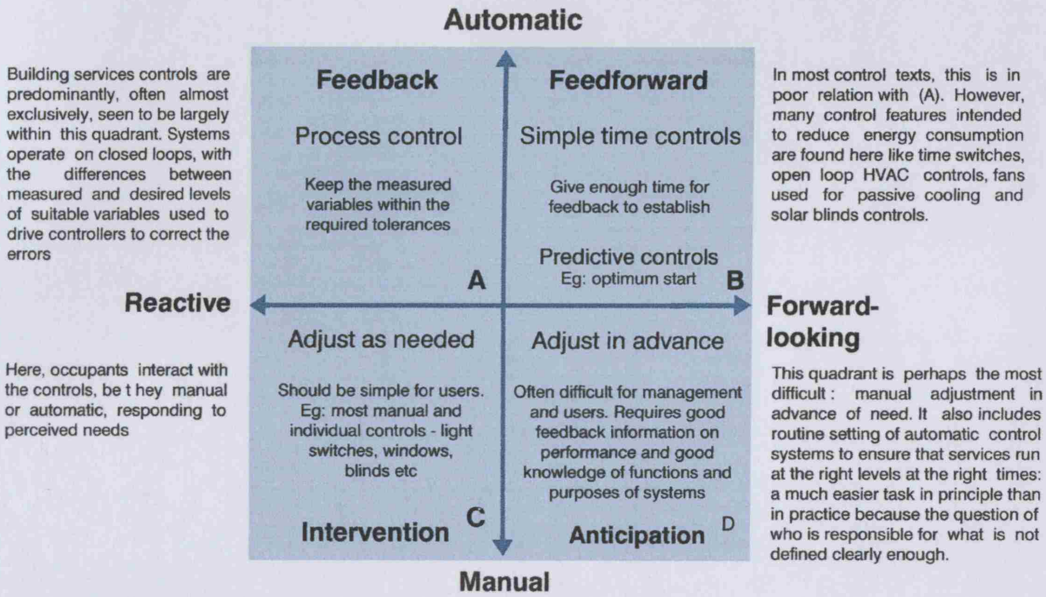
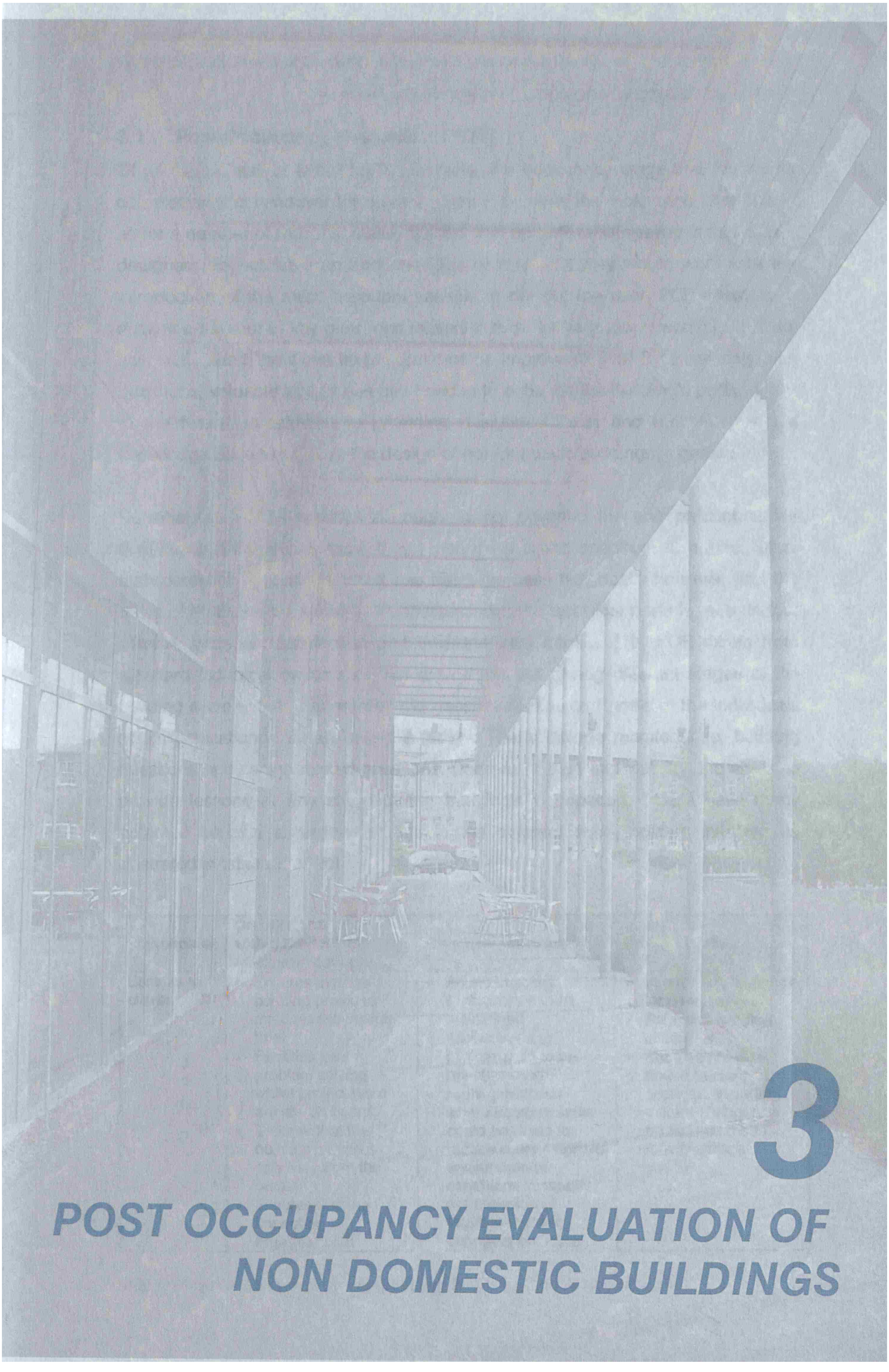


Figure (2.9):
Control strategies for building services, *Source [17]*

The ability to exercise some control over the built environment may have a crucial bearing upon the psychological satisfaction of occupants [18]. Therefore, one must not underestimate the value of approaching the issue from a broader spectrum as proposed by the previous model. It recognizes that the building is made up of a set of interacting elements that include the fabric of the building, its form, services systems and their control mechanisms [18]. In what is known as the Theory of Selective Design, it explicitly defines the needs and the role of occupants of a building in its environmental processes and overall performance, therefore heightening the importance of achieving targets for comfort conditions.



3

POST OCCUPANCY EVALUATION OF NON DOMESTIC BUILDINGS

3.1 Post Occupancy Evaluation (POE)

Of all the phases in a building's life cycle, the occupancy stage that follows its completion and handover for up to 2 years is perhaps the most important. This is so for a number of reasons, mainly the fact that up until buildings reach this phase, designers do not have an accurate idea of how well they would work with the introduction of the most important variable in design: the user. POE attempts to answer a number of key questions related to this: "Is the building working?", "if so, how well?" and "how can its performance be improved?" [19] By answering such questions, valuable insight can be provided to enhance the building's performance in the future, in addition to providing designers, users and managers with a knowledge base to improve the design of non-domestic buildings in general.

So what are POE's exactly? Although mainly covering the end product or the building and its performance, they touch on a broad spectrum of issues, either individually or in combination. It has been the case historically however, that the roots of POE can be found in architectural design, technical performance, indoor climate, occupant satisfaction and environmental impact. [19] POE differs from standard technical evaluations that are carried out during different stages of the building cycle in that it addresses the needs, activities and goals of the individuals and organizations that are using a facility. These include maintenance, building questions and design related questions. Because of their applicability and ability to provide lessons at any stage during buildings' occupation, POE's have many potential benefits at various stages to the different stake holders involved as illustrated in table (3.1).[20]

Stakeholder	On occupation, or within the first 12 months of occupancy	On an annual basis	Prior to move
Benefits to clients	• Ensures that the building provided matches the design brief • Facilities joint problem solving whilst project team are still on board • Ensures that the building operates optimally from the outset • Ensures that the impact on organizational	• Allows building performance to be maintained • Allows building performance to be benchmarked • Highlights areas where improvements could be made to reduce costs, improve environmental conditions or modify the provision of facilities to meet changing business	• Informs requirements for new premises • Prioritizes funding allocation • Secures pre-move buy-in to planned changes, including culture changes to be facilitated by the new premises

	performance is as intended	needs • Avoids complacency	
Benefits to end users	• Ensures that the quality of the working environment is satisfactory • Ensures that end users understand and are able to exploit the means to control their working environment • Ensures that facilities provision is suitable	• Ensures continuing satisfaction with the internal environment and facilities provision • Demonstrates the commitment of an organization to providing staff with a suitable workspace	• Allows staff to inform the brief for subsequent premises • Allows staff to voice their concerns
Benefits to facilities managers	• Ensures that they understand the building operation • Ensures that they are aware of likely problem areas for subsequent monitoring • Enables them to discuss any problems with the design team	• Allows the facilities team to interact positively and proactively with the end users • Allows the facilities team to prioritize their funding allocation • Allows the facilities team to demonstrate the value of their own performance	• Allows the facilities team to inform the brief for subsequent premises, avoiding past deficiencies
Benefits to the project team	• Provides immediate feedback and the opportunity to resolve problems jointly in a mutually supportive atmosphere • Is a learning experience for all staff within the organizations	• The maintenance of ongoing customer relationships	• The development of a better informed brief and smoother design process

Table (3.1): Benefits of POE at different stages of building occupancy, *Source [20]*

However, despite all the benefits of its application, a CRISP study carried out by the BRE has shown a range of barriers o the use of POE, including: [20]

- The reluctance of some clients to spend more time and money on evaluation procedures after the building's completion after already done so during its construction, not to mention their fear of the consequences that poor results of an evaluation process of their building might have on future projects.
- The project team themselves feeling constrained from carrying out a POE, needing the permission and cooperation of clients and building occupants.
- The fact that some occupants believe that a POE might be disruptive as it is after having to move into a new environment that requires them to adjust to. Moreover, management of the new facility might be faced with problems that might occur as a POE highlights something that occupants have already

expressed their dissatisfaction with in the building, augmenting complaints without providing solutions.

Nevertheless, the importance of POE cannot be undermined, particularly with the growing demand for energy efficient solutions to the built environment. Adopting the lessons learned from how a building works and fine tuning them is essential in improving the economic and environmental performance of buildings and achieving greater user satisfaction. [21] This cyclical process is illustrated in figure (3.1), where POE findings can be incorporated into strategies for procuring, occupying and managing buildings.

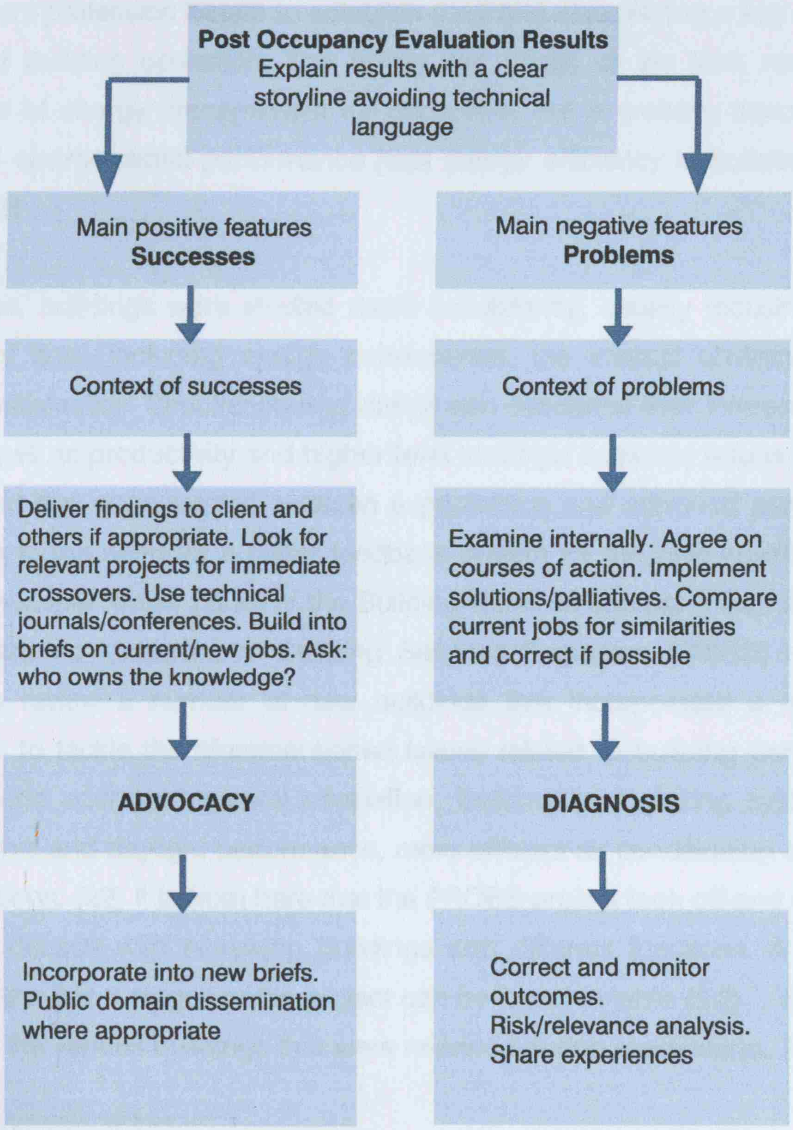


Figure (3.1):
The building performance evaluation (BPE) process model, *Source [21]*

3.2 The PROBE Project

The project for the post occupancy review of buildings and their engineering (PROBE) was initiated during the early 1990's to provide feedback to building services engineers of generic and specific information on factors for success and areas of disappointment in a building's performance. It was a little earlier than that during the 1980's that designers were facing increasing pressure from competition, government and clients to improve the speed and quality of the construction industry and reduce its costs. Buildings in general had to adapt to the needs if information technology and were used more intensively and changeably, therefore, requiring more services including air conditioning. Furthermore, the facilities management profession began to establish itself and was playing a key role in the process of building operation. The falling fuel prices at the time reduced the importance of energy management for occupiers, but a growing concern for all aspects of environmental performance kept energy efficiency in buildings on the agenda.[22]

At that time, buildings were studied more consistently, usually focusing on one issue every time, including energy performance, the internal environment and occupant satisfaction. Simultaneously, clients also expanded their interests in these issues as well as productivity and higher level strategic business issues. However, it was found that gaps existed between expectations and achieved performance, giving birth to the need for a better feedback system for the built environment. In 1994, the editorial review panel of the Building Services Journal (BSJ), the journal of the Chartered Institution of Building Services Engineers (CIBSE) started an initiative to review a number of new buildings that incorporated a number of innovations to tackle the aforementioned issues related to building performance. These include advanced natural ventilation, building and glazing systems with better thermal and daylight performance, more efficient air conditioning and mixed mode solutions. [22] It is from here that the PROBE project took off and continued for over a decade with reviewing buildings with different functions. A summary timeline of the first 3 stages of the project can be found in table (3.2)**, with a brief idea about the various buildings that were reviewed during every stage. The overall

** Information in the table is given for the PROBE projects that were carried out before the publication of the paper by Cohen R, Standeven M, Bordass B and Leaman A, *Assessing Building Performance in Use 1: The PROBE Process*, Building Research and Information (2001) 29 (2), Spon Press, 2001, p. 85-102. Further information about later PROBE projects can be found on the website of the BUS: www.usablebuildings.co.uk project now includes over 23 PROBE's, with more buildings and technologies examined through every stage that accompany the developments in low energy design of non domestic buildings.

Stage/Project	Time of implementation	Description
PROBE (1)	Mid 1995	The project started with Halcrow Gilbert, Building Use Studies Ltd (BUS) and William Bordass Associates as the team. It investigated 4 air conditioned offices, 3 educational buildings with advanced natural ventilation and 1 low energy medical center.
PROBE (2)	Early 1997	The scope of the project was increased to include procurement issues, water economy and a pressure test for envelope air tightness. It included another 8 buildings: 3 offices (1 air conditioned, 1 with a mixed mode system and 1 that is naturally ventilated), 2 mixed mode educational buildings, a mixed mode courthouse and a naturally ventilated warehouse.
PROBE (3)	Late 1999	

Table (3.2): Outline and description of the first PROBE projects, *Source [22]*

An outline of the PROBE survey and reporting process is shown in figure (3.2). In order for the procedure to produce enough rigorous and credible reports as it has been for the past 10 years or so, it was essential to adopt standardized methods and use existing techniques and benchmarks where possible. The 2 main tools used in the project are: [22]

- The occupant survey method developed by BUS to measure and analyze occupants' satisfaction with internal conditions
- A prototype of the Energy Assessment and Reporting Method's (EARM™) Office Assessment Method (OAM) for the analysis of energy use, which was developed and tested by the PROBE team and published (CIBSE, 1999), a flowchart of which is shown in figure (3.3).

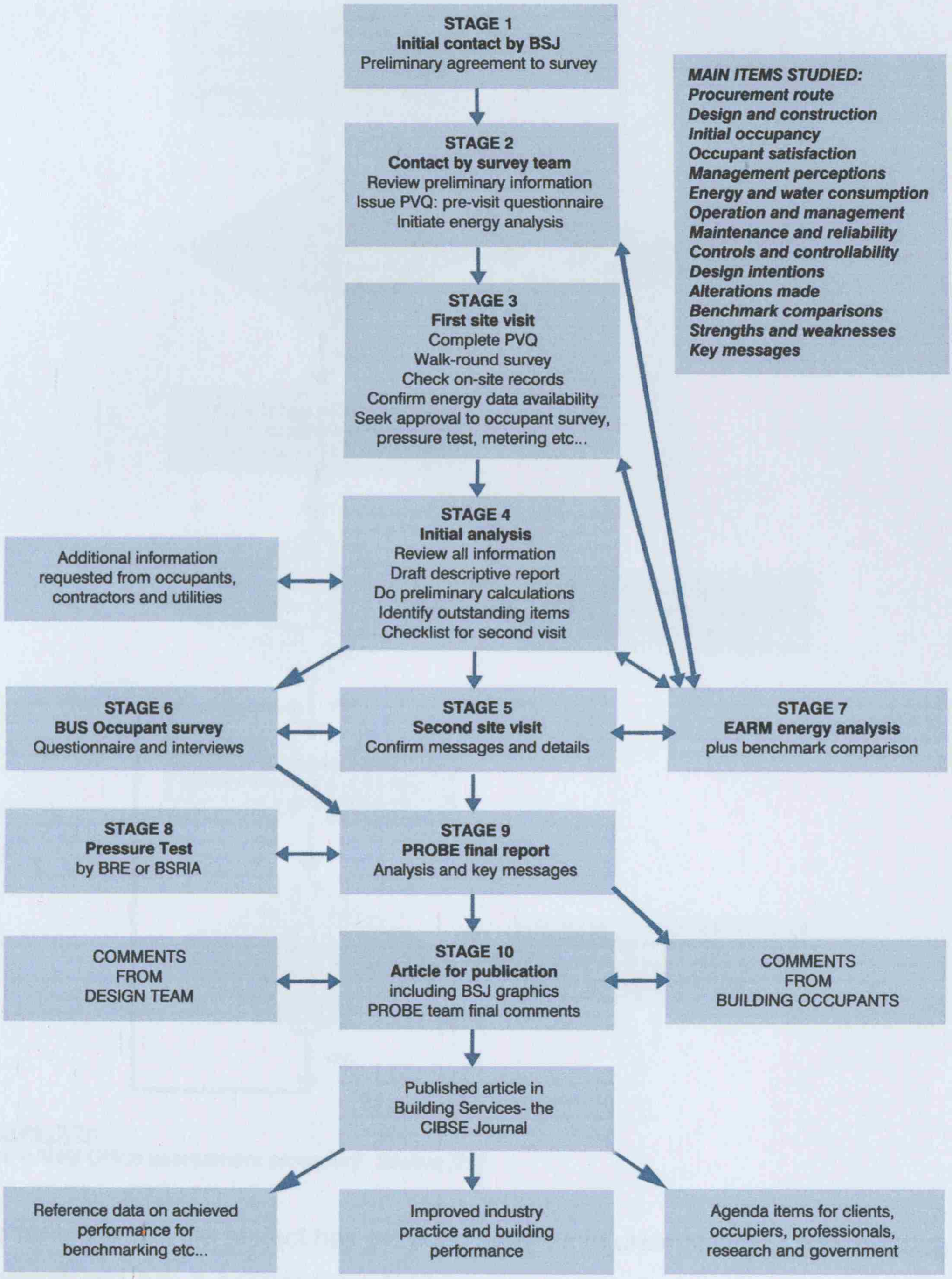


Figure (3.2):
Flowchart of the PROBE survey and reporting process, *Source [22]*

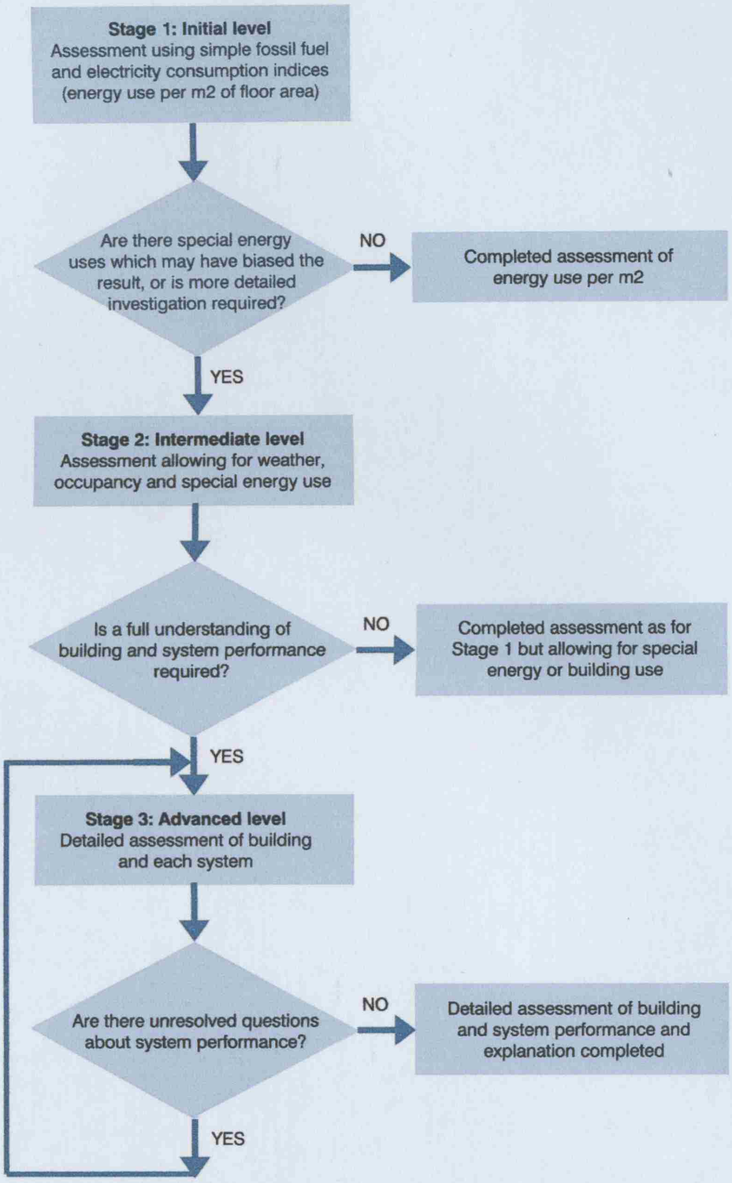
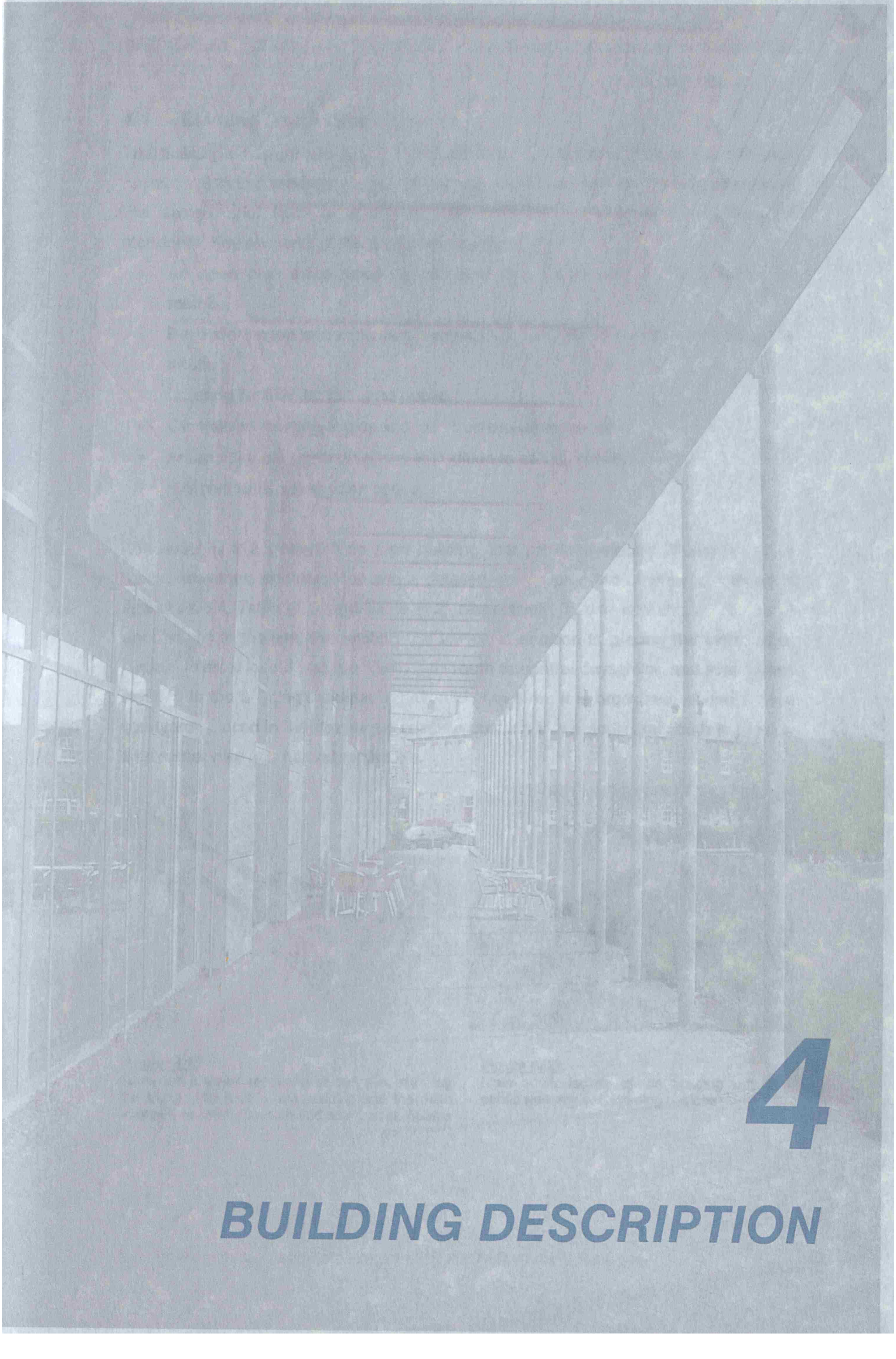


Figure (3.3):
The EARM Office assessment procedure, *Source [22]*

So far in the UK, the project has provided insight into understanding how buildings perform and has broadened the field for discussion of where problems are and what measures required to solve them. Furthermore, PROBE has proved the possibility of conducting a series of post occupancy surveys of different building types and making the results available in the public domain for all stakeholders involved to access and benefits from, which to the knowledge of Cohen R, Standeven M, Bordass B and Leaman A has not been done before, making it a pioneering step towards achieving better results when it comes to the comparison of predicted and actual building performance targets and benchmarks.



4

BUILDING DESCRIPTION

4.1 Building description

The building's design was aimed at reflecting the industrial heritage of the site (see appendix 8.3) in a modern interpretation that could accommodate the requirements of the design brief from a functional point whilst maintaining high environmental standards. Key elements of the design brief included:

- An open plan office space to accommodate around 435 National Trust staff members
- Reception, shop and exhibition/membership recruitment area that is open to the public
- Catering facilities for staff and public
- Centralized meeting rooms and localized breakout spaces
- Around 148 car parking spaces in addition to service delivery access
- External landscaped open space

The result is a 2 storey; deep plan building that provides around 7000m² of office space, drawings, constructions and a detailed design program of which are found in Appendix 8.4, Table (4.1) and Table (4.2) respectively. Taking into account the main approaches to the site, the existing site layout, in addition to placing the main public faŋade, internal layout and roof due north-south to control daylighting and solar gains, resulted in the building's unique trapezoidal plan form. It is organized around 2 main courtyards placed in the deeper parts of the building in the north and south to provide an external view and natural ventilation.

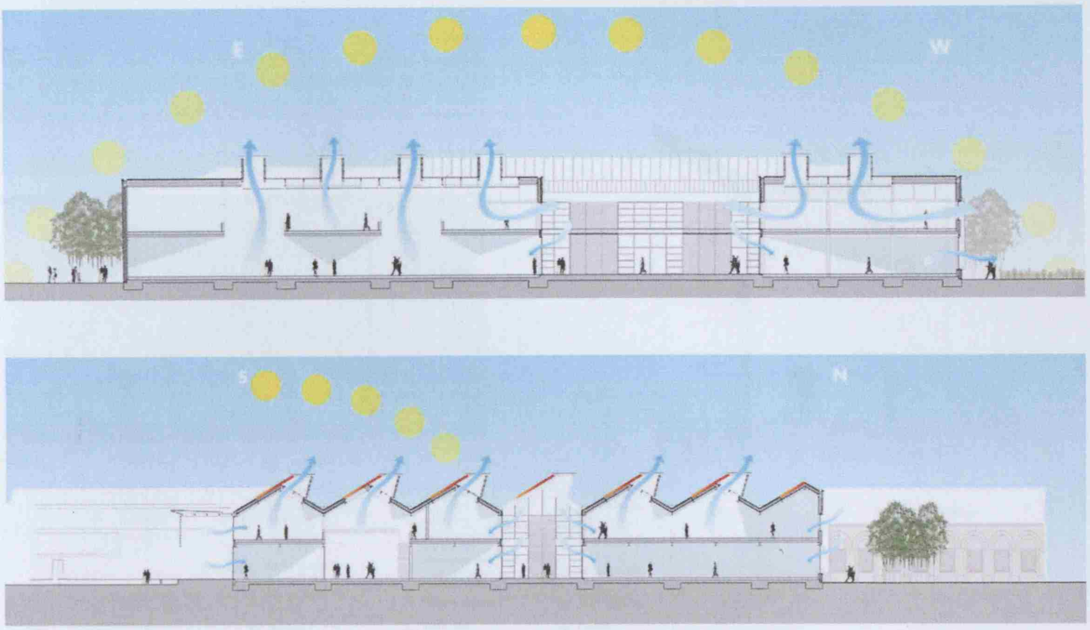
Figure (4.1):
Watercolour aerial rendering of the site, showing the trapezoidal form of the building and the main approaches from the south and south-west. *Source*

Figure (4.2):
Main south façade of the building with the public walkway and shading devices

The internal space of the building is characterized by a series of voids that connect the 2 floors both visually and physically (in the main atrium) and enhance the experience in the internal environment by allowing daylight to penetrate deep into the floors from the roof lights and courtyards as well as facilitating the movement of air between the ground floor and the first floor.

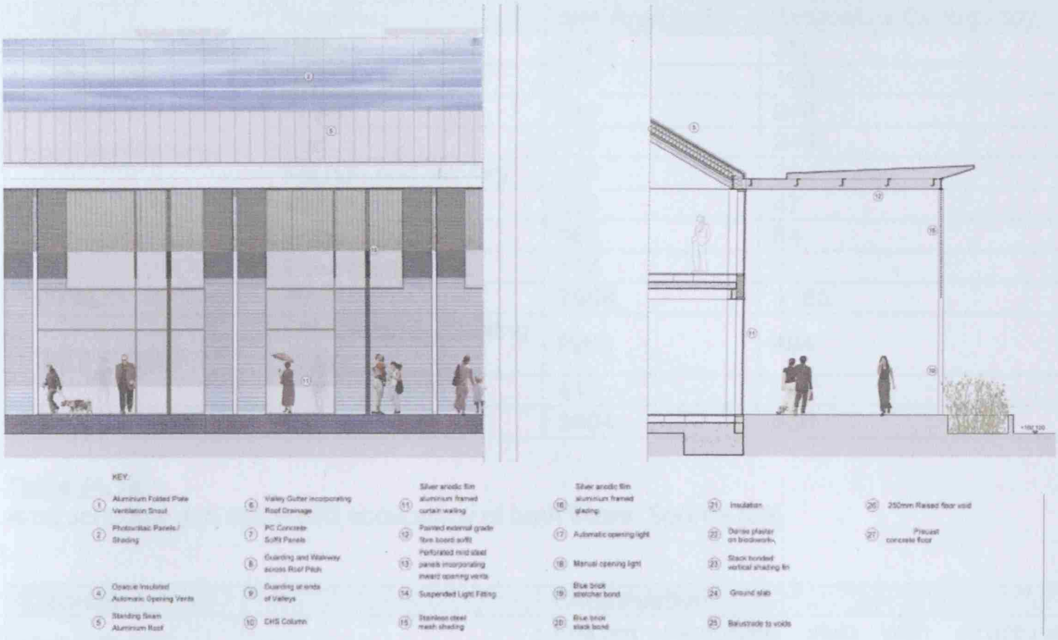
The building section reflects the "ridge and furrow" roof form that is used in many of the railway buildings and is driven by the need to maximize natural ventilation and daylight to all parts of working environment. Internal heights of the spaces, particularly on the ground floor are generous, which facilitates air movement even in the deeper parts of the building. Double height windows add to the spatial experience by allowing daylight to penetrate into the building, a feature that is enhance by the roof lights and transparent wall surfaces of the courtyards. The roof features a number of openings or "snouts" that allow for wind driven ventilation to occur no matter what the direction of the wind is.

Because they are inclined at an angle, they also provide shading to the roof lights. The roof provides thermal mass for summer night time cooling and is made up of 80mm thick exposed pre-cast concrete panels that are laid onto the internal steel structure with high levels of insulation above an aluminum external finish. Shading is provided to the south faŋade via a canopy that extends over it that includes a woven stainless steel mesh that projects down the columns on its southern edge.



<u>Figure (4.3)</u>:
North-south section (top) showing the openings in the roof or "snouts" which facilitate wind driven ventilation in the building, east-west section (bottom) showing voids within the office space between floors as well as the courtyards, all of which allow for daylight to penetrate through the deep plan and allow for natural ventilation of the internal environment, *Source [24]*

The building form is characterized by 3 main elevations made up of an outer skin that is comprised of Staffordshire blue engineering brick which is also used elsewhere in the site in addition to glazed openings with varying scales from double height windows to smaller single windows that reflect the volume of the spaces they serve. The inner skin is both highly glazed and transparent in some parts, while non-transparent surfaces in other ones are clad in substantial steel grilles. These are meant to eliminate the need for opening windows that would obstruct the movement of pedestrians in the public route to the south on the ground floor level for example. The same treatment is developed for the internal courtyard elevations where the steel is replaced by timber paneling.



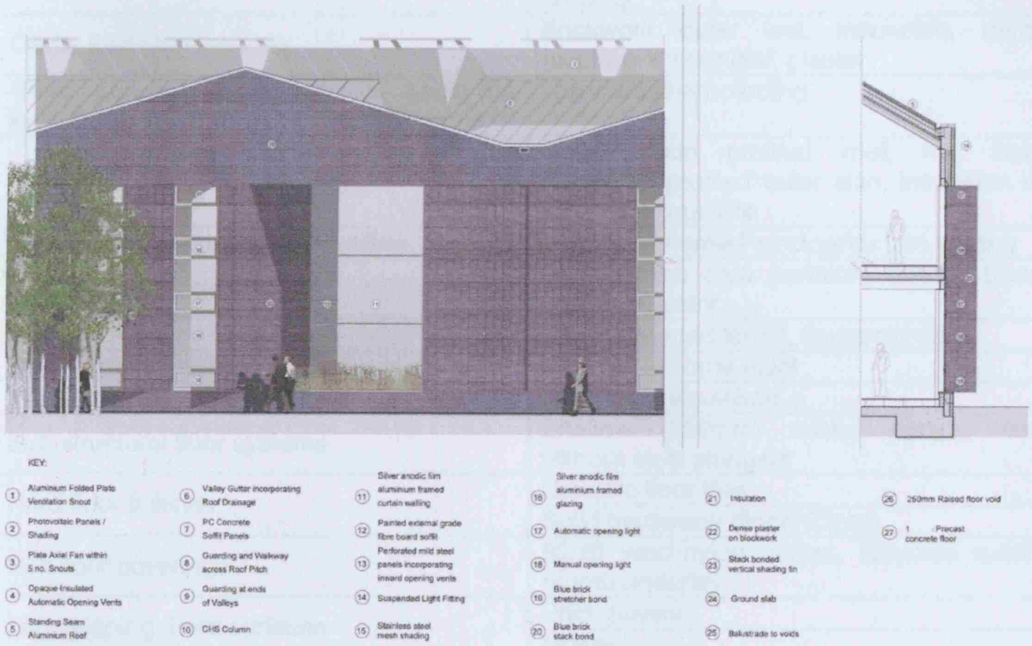


Figure (4.4):
Outer (top) and inner (bottom) skin detail studies showing the different materials that are used by designers to reflect both the functions and nature of the space within the building in addition to meeting various environmental targets regarding daylighting and natural ventilation, *Source [23]*

Level	Function	Net Area (m^2)	Estimated Occupancy
GROUND FLOOR	Offices	2167	362
	Meeting rooms	261	153
	Foyer	240	240
	Cafι	248	248
	Kitchen and servery	209	30
	Atrium	280	47
	Shop	168	84
	Plant room	116	2
TOTAL		**3689**	**1166**
FIRST FLOOR	Offices and meeting rooms	2960	494
	Comms. room	44	2
TOTAL		**3004**	**469**

Table (4.1):
Area schedule and estimated occupancy of both floors, Source [23]

Element	Construction
Upper Floors	Precast reinforced slab with structural topping
Cavity Wall Construction	Brickwork outer leaf, insulation, dense blockwork inner leaf, plaster
"Rain screen" Claddings to courtyard elevations	Larch weatherboarding
Pitched Roofs	Double skin profiled roof, mill finish aluminum profiled outer skin, insulation on steel roof structure
Window and glazed curtain walling	Aluminum framed window/curtain walling
Non load bearing partitions	Steel jumbo stud partition, plaster board and skim, paint
Internal Doors	Flush, plywood faced, flaxboard core
Internal paint finishes	Matt water borne paint
Insulation	Rock wool insulation
Sub-structural floor systems	Shallow (250mm) raised access floor without steel stringers
Hard floor finishes	Ceramic floor tiles
	Solid hardwood (floor) 22mm
Soft floor coverings	80/20 wool/nylon carpet, recycled rubber crumb underlay
Landscaping: hard surfaces	Brick pavers
	Gravel

Table (4.2):
Constructions for different building elements at the Heelis, Source [23]

Operational Energy Consumption and CO^2 Emissions	
CO^2 Emission Target	30kg $CO^2/m^2/yr$
Heating Load Target	47kWhr/m^2/yr
Electrical Load Target	43kWhr/m^2/yr
U-Values:	
Walls	0.2
Average Window	1.4
Roof	0.15
Ground Floor	0.2
Air tightness	<7m^3/hr/m^2
Ventilation	Designed natural ventilation with automatic vents, mechanical ventilation to WC's etc...
On site Energy Generation	Solar domestic water heating to WC's
Daylighting	80% office space day lit to meet criteria of BS8206: part 2
Artificial Lighting Controls	Luminance and presence detection at all fittings with dimming at zero and BMS override
Cooling Systems/Sources	Night time structural cooling with automatic window vents
Embodied Energy in Structural Materials	Use of cement replacements in concrete, use recycled steel
Materials used in the construction process	
Toxicity of materials	Eliminate PVC cabling, change to LSF. Avoid all "C" rated materials in BRE design guide
Materials Sourcing	Specify all heavyweight materials to be from local sources. Consider Recyclability and lifecycle costing of all materials
Insulation Materials	Use only materials from regenerative sources e.g. cellulose/wool/cork
Recyclability of Materials	High grade materials e.g. bricks to be designed for Recyclability e.g. using lime mortar
Waste Production During Construction	Contractor to commit to targets on waste production from site. Encourage prefabrication
Water and Waste Systems	
Water Usage	Waterless urinals. Hand PIR on tap operation
Drainage Systems	Use Sustainable Urban Drainage Systems, soak aways etc to reduce burden on sewage system.

Table (4.3):
Sustainability targets of some of the items included in the sustainability matrix that was set during early stages between the designing team and representatives from the National Trust, Source [23]

4.2 Key design strategies

4.2.1 Daylight strategy

The need for a well daylit building was clear from the early stages of design. This is due to the fact that, as shown in figure (4.5), the percentage of working hours for external diffuse light levels or daylight in an area like London, and similarly Swindon, will exceed 6000 lux for 80% of the year between 9am and 5pm [23]. That, coupled with the fact that artificial lighting in a naturally ventilated building can represent 30% of the running costs, a substantial amount of which can be cut down using good daylighting [23], led the design team to aim at achieving a minimum of 5% daylight factor in the office spaces at Heelis as much as possible.

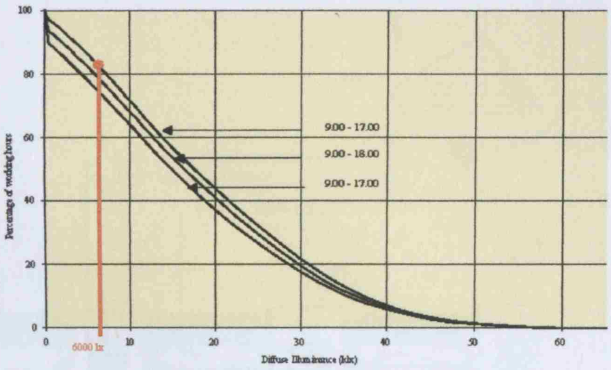


Figure (4.5):
uminance levels available in London, the figures from which are applicable to Swindon as well. *Source [23]*

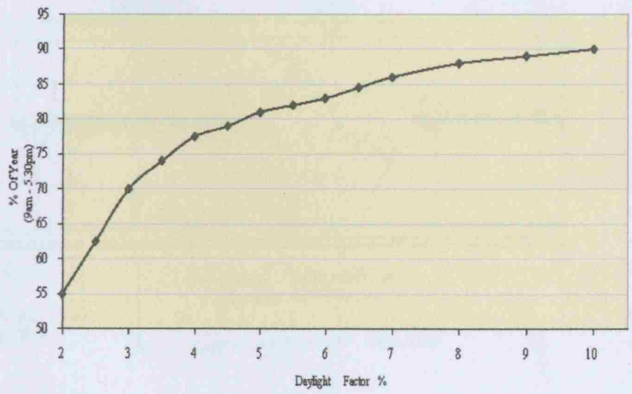


Figure (4.6):
Percentage of year natural internal daylight levels above 300 lux for various daylight factors. *Source [23]*

The design of the building itself reflects these aims. The mezzanines allow light from the roof lights to reach the ground floor abundantly as illustrated in figure (4.7). The roof lights are used as the main source of natural light and are oriented as north lights with external shading. This excludes most of the direct sunlight that might lead to overheating in addition to limiting glare during working hours. It was found during the design that positioning the mezzanines in a direction that is perpendicular to the roof lights would give the optimum light distribution. Locations where undesirable amounts of daylight were penetrating the building were used to place ventilation openings that have opaque opening roof lights, which in turn are protected by the “snouts” above them.

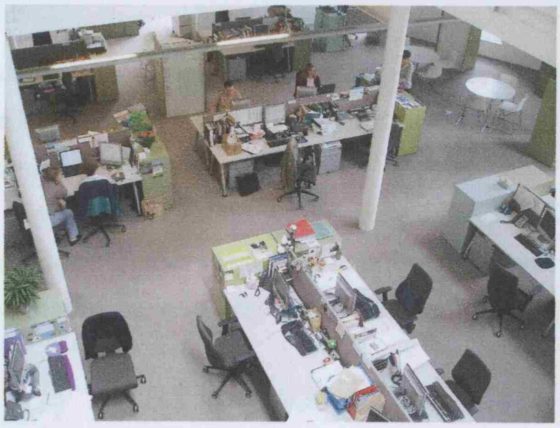


Figure (4.7):
View from one of the mezzanines looking down onto the office space below where natural lighting is used mainly with some artificial lighting in some corners that that are a bit more "dim"

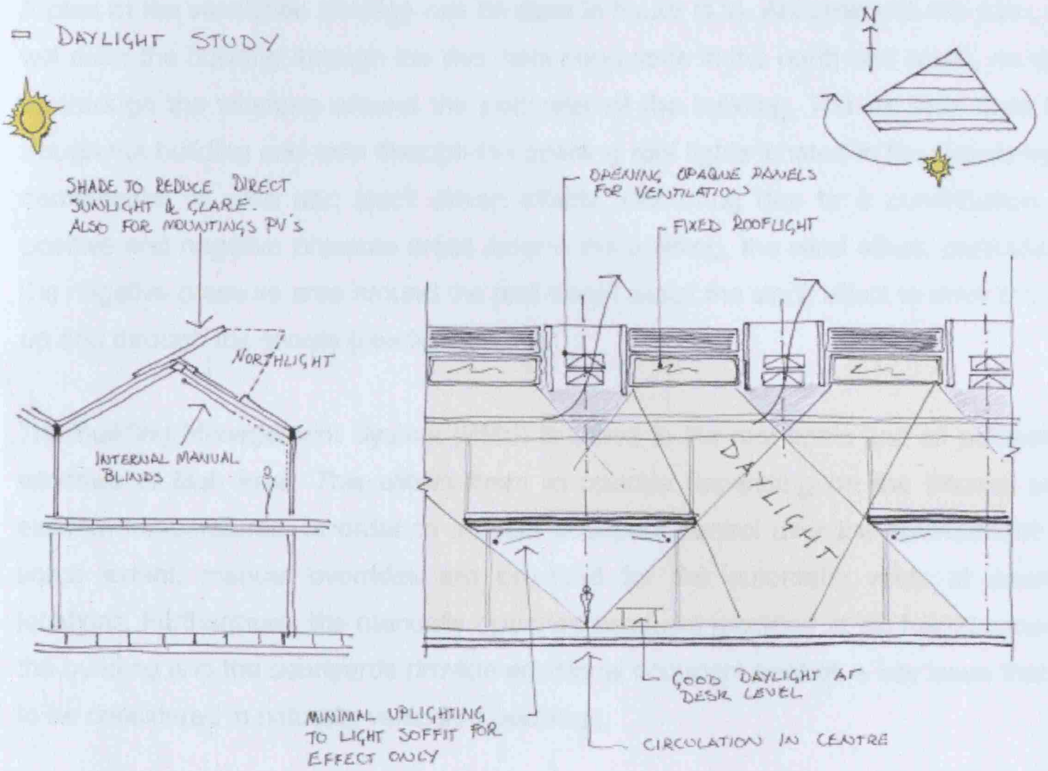


Figure (4.8):
Heelis daylight design strategy, *Source [23]*

4.2.2 Ventilation strategy

The Heelis building makes use of thermal mass and night time cooling in order to maximize the use of natural ventilation. The large areas of dense, exposed materials in the roof and concrete soffits of the mezzanine allow for the solar and internal heat gains to be absorbed during the day. The automated windows would open based on internal temperatures and during the night, allowing cool air to circulate through the building, which in turn, cools down the thermal mass, allowing for it to absorb more heat during the following day.

Summer time strategy:

A plan of the ventilation strategy can be seen in figure (4.9). According to the plan, air will enter the building through the two main courtyards in the north and south, as well as through the windows around the perimeter of the building. The air then rises up trough the building and exits through the opening roof lights located in the snouts by a combination of wind and stack driven effects. Occurring due to a combination of positive and negative pressure areas around the building, the wind effect, particularly the negative pressure area around the roof would assist the stack effect to drive the air up and through the snouts (see figure 4.10).

The Building Management System (BMS) is linked to the roof lights and all perimeter windows at high level. This allows them to operate depending on the internal and external temperatures. In order to provide occupant control over the environment to some extent, manual overrides are provided for the automatic vents at nearby locations. Furthermore, the manually operated windows provided at sill height around the building and the courtyards provide additional occupant control, a key issue that is to be considered in naturally ventilated buildings.

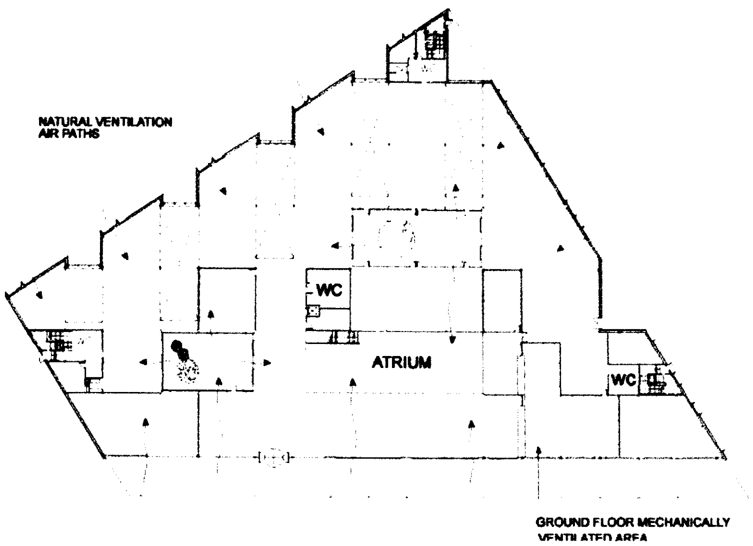


__Figure (4.9)__:
Plan of the ventilation strategy,
Source [23]

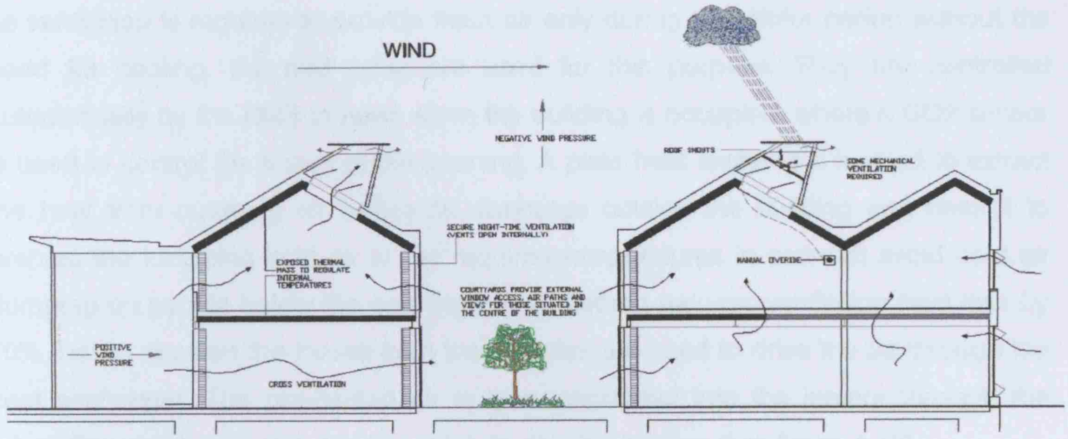


Figure (4.10):
North south section through the building showing ventilation strategy, *Source [23]*

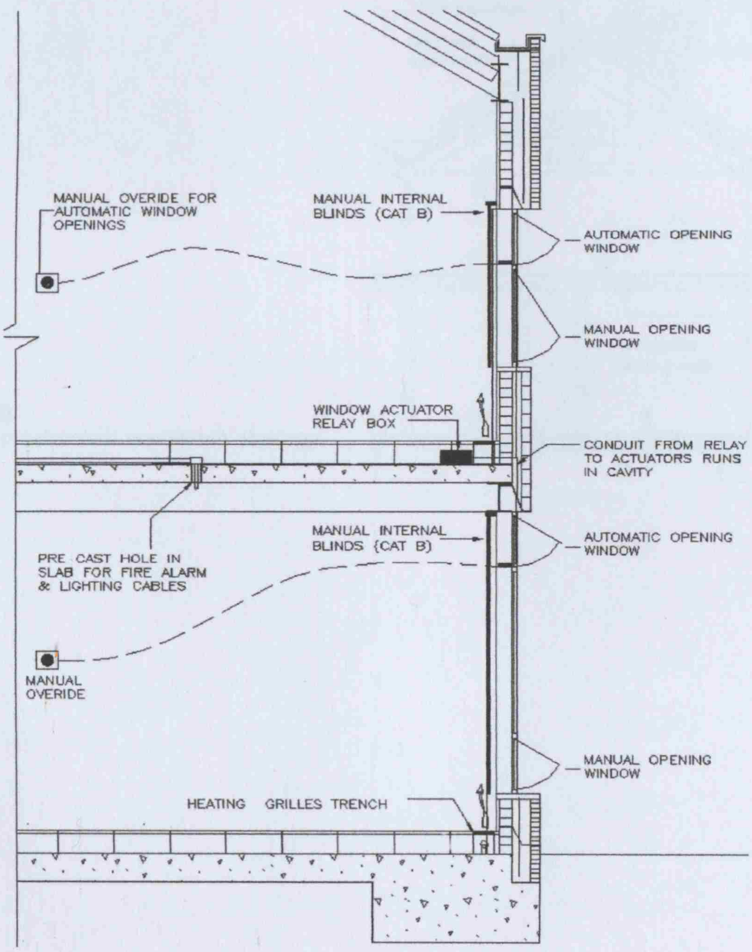


Figure (4.11):
Partial section through the perimeter of the building showing automatic openings and manual override controls, *Source [23]*

Winter time strategy:

As ventilation is required to provide fresh air only during the winter period without the need for cooling, the roof lights are used for this purpose. They are controlled automatically by the BMS to open when the building is occupied, where a CO2 sensor is used to control the extent of the opening. A plate heat exchanger is used to extract the heat from outgoing air before its discharge outside the building and uses it to preheat the incoming cold air to the required temperatures in order to avoid cold air dumping on people below the openings. This method reduces ventilation heat loss by 70%, not to mention the losses from the fans that are used to drive the air through the heat exchanger. The pre-heated air is then introduced into the interior through the raised floor void and extracted from high level extract grilles (see figure 4.12).

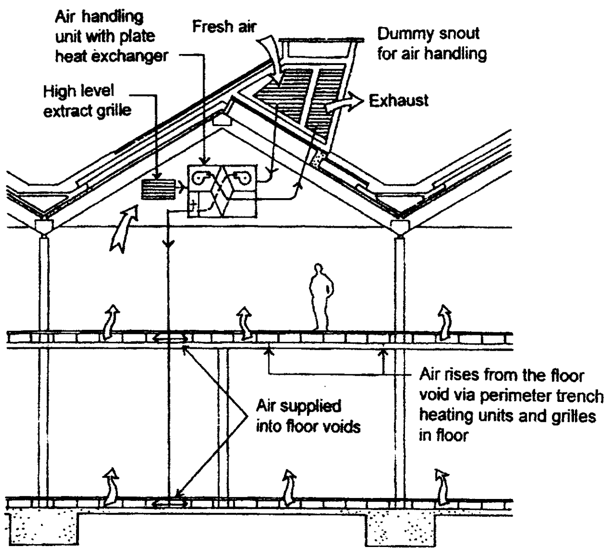


Figure (4.12):
Winter time mechanical ventilation strategy, *Source [24]*

4.3 Predictions

4.3.1 Thermal modelling

In order to test the performance of the building with the parameters defined during the design process, particularly for solar shading, ventilation and thermal mass, a computer simulation model was used. It started with a simple thermal model to help define the parameters of the building where construction materials and the area of openings were set up. However, because of the intricate nature of the building, a more complex model was later developed to test the design in more detail so that comfort conditions and targets would be met. TAS simulation software was used for this purpose, where the office spaces were divided up into relatively large zones to keep the model easier to modify and manipulate during various test runs (see figure).

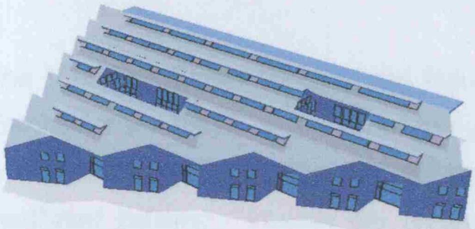


Figure (4.13):
Perspective view of the TAS model, *Source [23]*

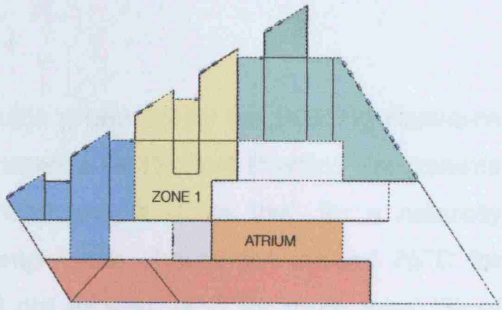


Figure (4.14):
Zoning of the building for the TAS simulation model, *Source [23]*

Using the BRE '97 weather files, a number of runs were carried out to predict the performance of the building and to measure the strength of the design. The base model used the following internal conditions for the simulation:

Element	Description	Heat gain
People (sensible)*	A maximum occupancy of 430 people, 80% of which would be present at any one time or 344 people	7.5 W/m²
People (latent)*	As above	3 W/m²
Computers*	Normal screen computers at 120W each, with 15% laptops at 50W. Allowance is considered for printers and other devices.	9 W/m²
Lighting	For hot sunny days, controls only switch on 25% of the time	3 W/m²

* Occupancy and computer use were suggested by the National Trust as being typical. For the atrium, an average of 10 people, with 100 people for an hour at 5pm was modeled. Lighting was assumed to be on for only 25% of the time.

Table (4.4): Internal Conditions for TAS simulation, *Source [23]*

After running the simulation for the base case, a number of further runs were carried out to provide further analysis as follows:

1. Base case with the aforementioned gains in table (4.4) and fans running in the "snouts"
2. Base case with the snout fans running
3. Base case with higher internal gains (full occupancy with 450 people all with normal screen computers)
4. Base case with Audex sound absorbing materials applied to the soffits of the mezzanine and roof
5. Base case with only 2/3 of the snouts
6. Base case with rockwool type sound absorbing material to roughly 25% of the roof, replacing the concrete
7. Audex with only 2/3 of the snouts

The "Energy Efficient Office of the Future" guide produced by the Building Research Establishment (BRE) on behalf of the government's DETR Best Practice Programme was referred to for design targets and benchmarks. It states that, for a naturally ventilated building, "internal dry resultant temperature should not exceed 25°C for more than 5% of working hours and should not exceed 28°C for more than 1% of working hours" [23]. These maximum values were used to compare the results obtained from the different simulation runs, seen in figures (4.15) and (4.16).

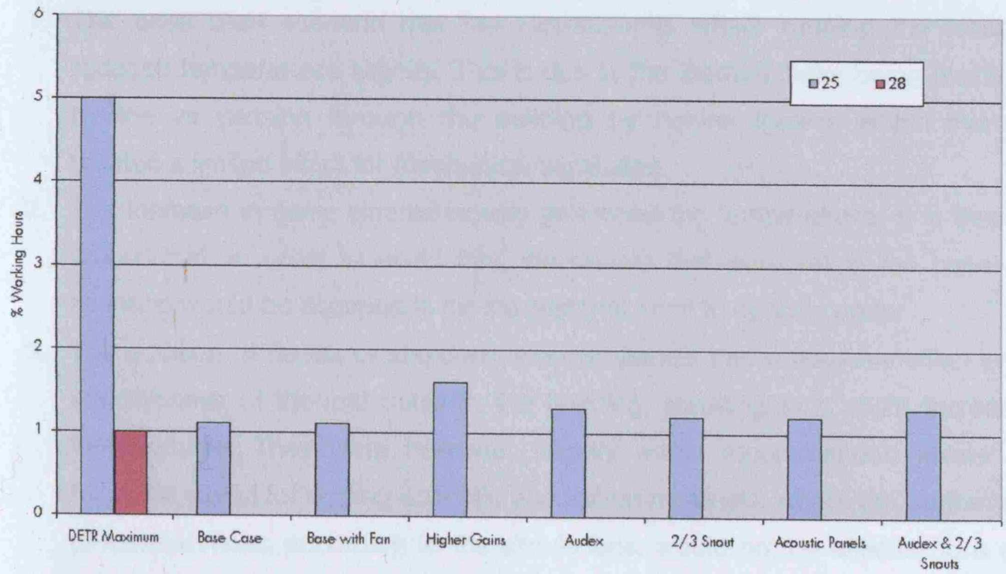


Figure (4.15):
Results from TAS simulations showing Ground Floor % working hours over 25°C and 28°C, *Source [23]*

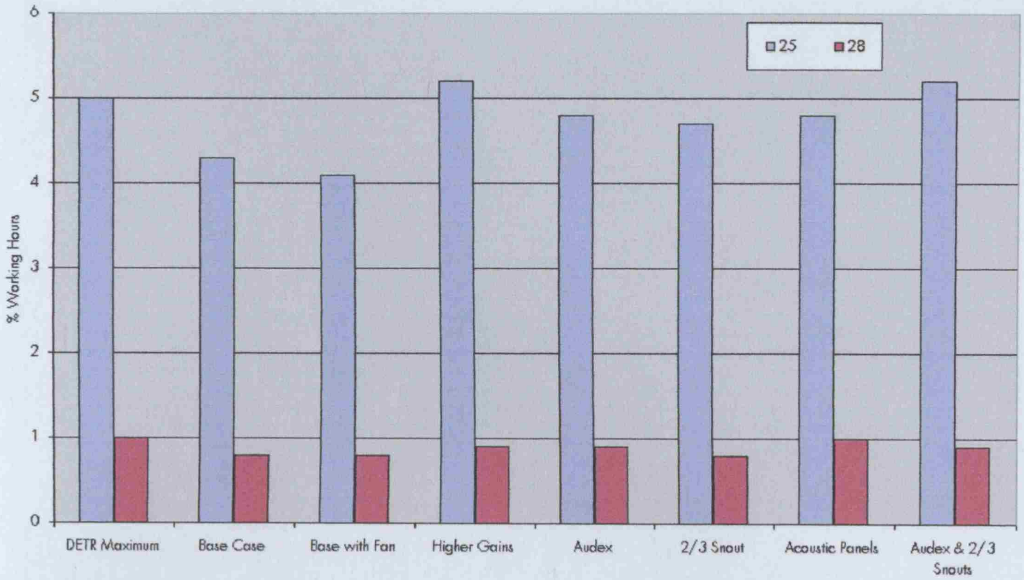


Figure (4.16):
Results from TAS simulations showing First Floor % working hours over 25˚C and 28˚C, *Source [23]*

As one might expect, the results for the first floor were much closer to the maximum values set by DETR. The following observations were noted by the designers regarding the performance of the first floor:

1. The base case scenario met the requirements where running the fans only reduced temperatures slightly. This is due to the thermal mass being maximized by the air passing through the building by natural means, which therefore, created a limited effect for mechanical ventilation.
2. The increase in gains simultaneously increased the temperatures. It is therefore crucial that, in order to avoid this, the targets that were set in the base case scenario would be acceptable for the National Trust to operate under.
3. The addition of Audex or standard acoustic panels had a negative effect on the effectiveness of thermal mass in the building, resulting in a slight increase in temperatures. They were however, slightly within recommended levels. This might be useful for adding acoustic absorption materials, where the performance of thermal mass, according to the simulations, would not be affected to a great extent.
4. A reduction in the number of ventilation snouts by 1/3 increased the temperatures. If a reduction is combined with the addition of acoustic absorbent materials, temperatures would exceed maximum recommended levels.

Figure (4.17) below shows the internal dry resultant temperatures on the ground and first floors for zone 1, which is a typical office space, and the atrium for a typical day in July. The peak external temperature in this case is 25°C. Figure (4.18) on the other hand, shows the internal dry resultant temperatures for a hot summer day where the peak external temperature reaches 30°C. According to the graphs, which are the results for the base case scenario with added Audex acoustic insulation, the internal temperatures will have fewer fluctuations than external conditions. Furthermore, the maximum temperature peaks at the same external one on a typical day but is less that that of a very hot summer day.

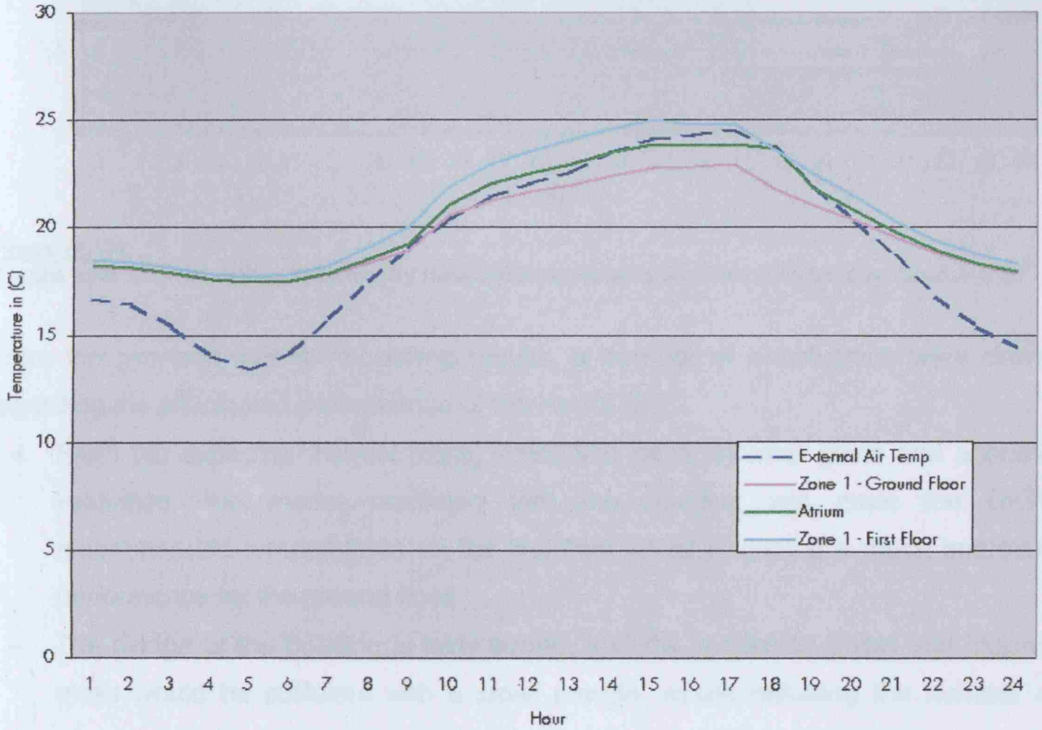


Figure (4.17):
Results from TAS simulations showing dry resultant temperatures for a typical July day, *Source [23]*

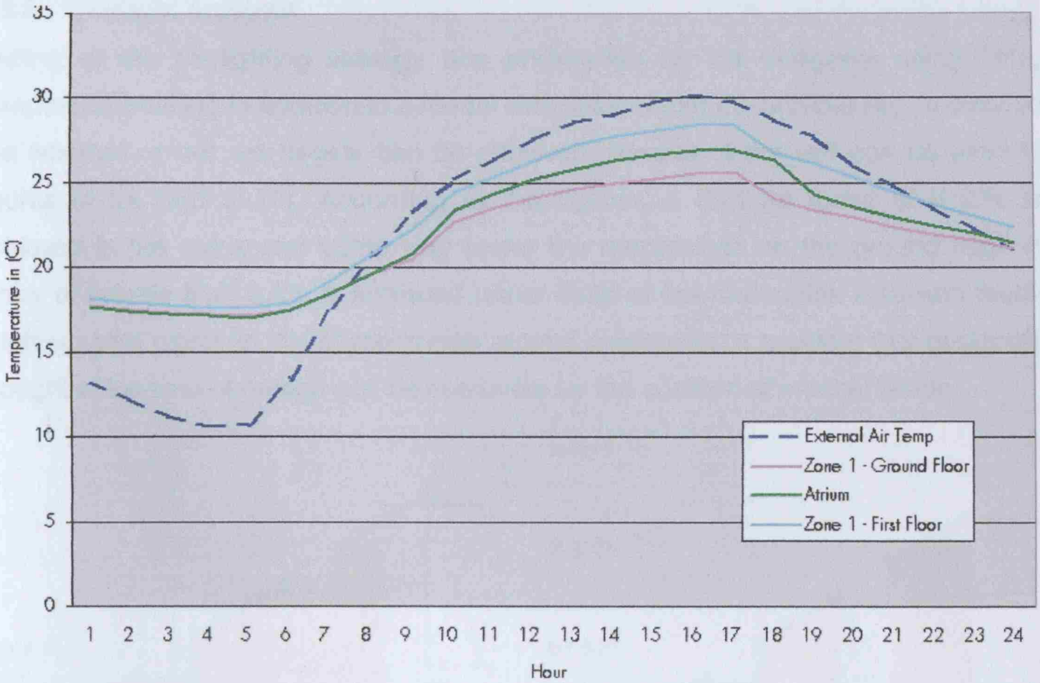


Figure (4.18):
Results from TAS simulations showing dry resultant temperatures for a hot summer day, *Source [23]*

From the previous thermal modelling results, a number of conclusions were drawn regarding the anticipated performance of the Heelis [23]:

- From the expected thermal mass, ventilation rates, internal gains and acoustic insulation, the model predicted that the building will meet the DETR recommended temperatures on the first floor whilst providing a much improved performance for the ground floor.
- The design of the building is fairly strong, and the ventilation levels and thermal mass would be sufficient with a small margin, where reducing the number of snouts or thermal mass would have an effect but a relatively limited one.
- The number of ventilation snouts should remain as that of the design. There can be a reduction however, in the number of fans, but proper power supply and control should be provided for future retrofitting.

4.3.2 Daylight analysis

Testing of the daylighting strategy was undertaken by the designers using both, computer modelling in addition to a model simulation under the artificial sky, in order to test whether or not set targets can be achieved. Results of the test can be seen in figures (4.19) and (4.20). According to the figures, a daylight factor of 5-10% is achieved in the voids and some way under the mezzanines on the ground floor. A factor of greater than 2.5% is achieved under most of the mezzanine area with much brighter spots closer to the glazed areas around courtyards, a problem that designers thought at the time of design can be overcome by the addition of internal blinds.

Figure (4.19):
Ground floor daylight factor distribution, *Source [23]*

Figure (4.20):
First floor daylight factor distribution, *Source [23]*

On the first floor, daylight factors of 5-10% are achievable over most of the floor according to figure (4.20). The perimeter of the building would be lower as there no roof lights directly above offices in that area and again brighter spots occur directly underneath the roof lights in addition to the areas right next to the courtyards. Overall, the results from the simulation were encouraging as they are well above the benchmarks set by BS8206. Further, more detailed tests were recommended in later stages of the design in order to determine the effect of reducing the transmission factor of glazing directly above the mezzanines to try to improve the uniformity across the space. These showed that lower transmission factors improved the uniformity on the first floor but had little effect on light levels on the ground floor.

A set of tests to determine sunlight penetration into the building was also carried out in order to see if the provided external shading would be sufficient. The tests from the artificial sky have shown that no direst sunlight would enter the building the building through the roof lights or the west faɲade until 5pm on June 22nd, when sunlight is most likely to enter the building. However, tests did not include simulating east facing windows where the designers have indicated the existence of some external shading that should be sufficient because the sun will not be in the east after 10am on June 22nd. In addition, it was suggested that in order to solve glare, a common problem associated with many office buildings, particularly with the use of computers, flat screens should be used as they also reduce internal heat gains in the space. It was also recommended that internal manually operated blinds are provided to all roof lights and windows so that occupants can reduce the brightness levels if required.

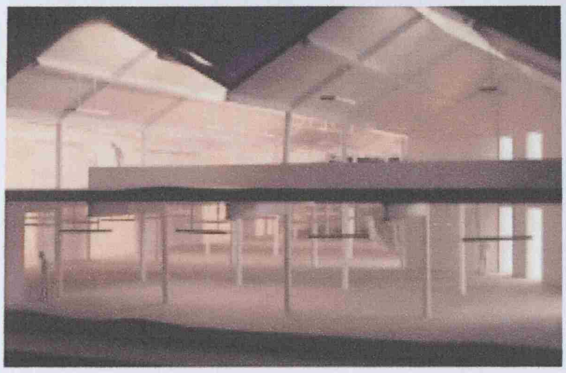


Figure (4.21):
Image of the Heelis model simulation under the artificial sky on June 22nd where no direct sun light enters the building through the roof lights and west facade, *Source [23]*

4.4 Review of building performance

After its completion, the Heelis was recognized for its high standard building performance, and went on to win a number of awards including the RIBA Sustainability Award, the AJ Sustainability Award and the BIFM Building of the Year and Sustainability Awards, all in 2006. A question however, emerges through all the titles and accomplishments: how well did the Heelis really perform in its post occupancy stage and were the targets set by designers met; and if so, to what extent? In order to address these crucial issues, the designing team has monitored the building during the first 18 months of its occupation as part of an ongoing mission to examine the building performance with respect to the targets that were set during the design stage. A number of key studies were conducted during the process, including a building energy review, a building occupant survey and monitoring of heating, ventilation and energy use during 2006.

4.4.1 Building Energy Review – Bill Bordass [25]

In his review of the Heelis, Bill Bordass from The Usable Buildings Trust highlights a number of key points that relate to the energy performance of the building during 2006. According to Bordass, despite room for improvement in a number of areas, the building in general compares well with other buildings. Figure (4.22) below shows the annual CO2 emissions per square meter of treated floor area for a number of low energy academic and office buildings, many of which were included in the PROBE database of buildings studied across the UK. According to the graph, although there is a marked increase in CO2 emissions between the preliminary figures for the Heelis and those for 2006, the building remains well ahead of other low energy buildings, reaching Good Practice targets after CIBSE TM22 corrections and before PV deductions.

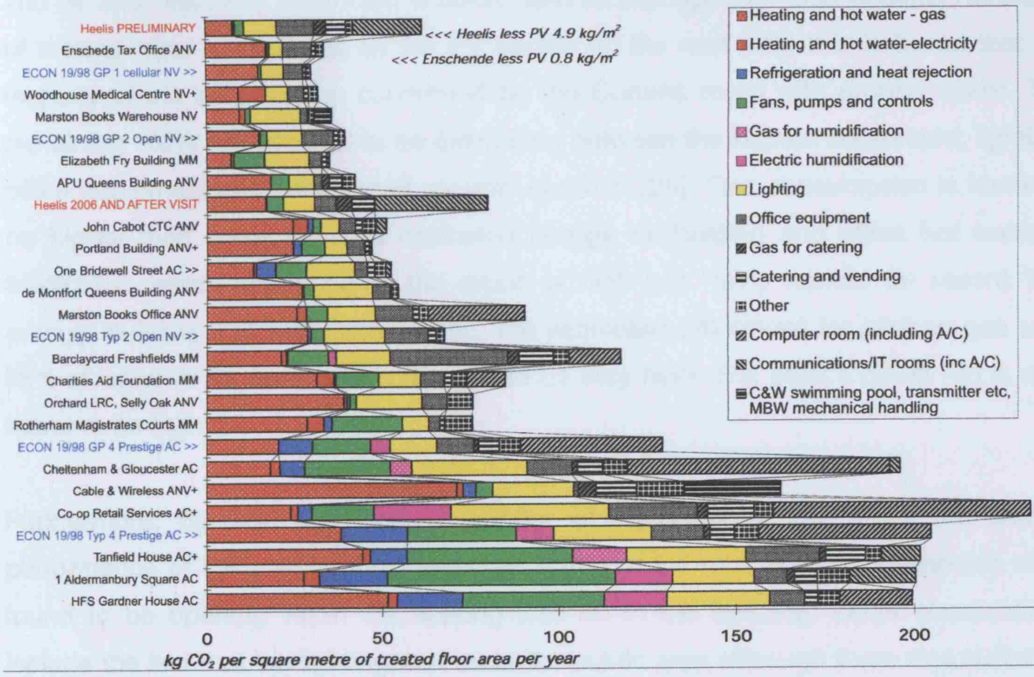


Figure (4.22):
CO2 emissions and energy consumption for the Heelis in comparison with other low energy educational and office buildings included in the PROBE dataset, *Source [25]*

A summary of the performance of the different building systems is found in table (4.5) below:

System	Performance
Heating and hot water system (HWS)	Good practice – could do better
Fans, pumps, controls	Not bad, could do better
Cooling (in the comms room)	Could do better
Lighting	Good practice – could do better
Office equipment	Low, some scope to improve
Catering kitchen (including ventilation and HWS)	HIGH
Comms room (including cooling system)	HIGH

Table (4.5): Summary of systems energy performance at the Heelis for 2006, *Source [27]*

In addition, some of the main issues that are highlighted in the review include electricity and gas consumption, which in some cases are quite high for a building like the Heelis. The 24 hour electricity base load is 55kW, with an average total load of 80kW, inclusive of around 10kW contributed by the PV panels on the roof [25]. It is believed that the majority of the base load is consumed by the Comms room with around 45kW. The remaining 10kW are believed to be distributed between the kitchen equipment, lighting, office equipment and control and security systems [25]. Gas consumption is found to be higher than predicted. The estimated energy for heating and office hot water is 90kWh/m^2, which according to the report is high but "fairly normal for recent 'low energy' buildings". On the other hand, the estimated 24kWh/m^2 for kitchen gas use, 75% of which is for hot water is thought to be very high. The plant's hours run is also found to be high.

Furthermore, Bordass highlights a number of observations that affect the energy performance of the building. For example, some of the roof lights and windows were found to be opening when the heating was on in the building. Other observations include the fact that the lighting was on in the public area although there was sufficient daylighting in addition to the kitchen extract fan being left running on high power even when there was no cooking being done. These observations are important in the sense that they emphasize the importance of involving the building or energy management in every aspect of the building operation to form a link between the occupants and the building systems. This link would ensure that all systems are running more efficiently without any damage occurring due to malpractice that results from the occupants' wish to override the system to achieve better levels of comfort in the building. This in itself leads back to yet another issue that Bordass has brought up quite extensively through his report: perceived inaccuracies and shortcoming in the metering and monitoring systems within the BMS.

The Building Energy Review proposed a number of recommendations that are to be addressed if the building is to run more efficiently [27]. These include:

- The possibility to alter the BMS to include more alarms that can be used for example when the heating is on and windows open simultaneously.
- Appointing an energy manager for the site
- Reviewing the user guide to ensure that it is clear for new staff and future employees
- Training members of the staff in BMS and lighting management systems
- Calibrating and logging meters and considering adding more of them
- Tweaking control settings and time schedules
- Reviewing user interfaces
- Reviewing the operation of the kitchen
- Reviewing chilled water operation and cooling of the comms room
- Doing a night survey to review the base energy loads for the building

From the aforementioned recommendations, one will easily observe the relationship between occupant control, performance monitoring and facilities management. They highlight the need for adopting a system of management that would enable feedback from the occupants and specialists simultaneously to improve on the building's performance. Moreover, the issue of documentation of both monitoring results and building operation takes center stage. Users are to understand how the building works in order for them to interact with their environment more safely and efficiently. The idea of having a user guide for the building is an innovative approach to bridging the gap between occupants' understanding of it, only if it is updated regularly and made accessible to users with room for queries that they might have.

Finally, Bordass's report shows that, particularly in "low energy" buildings, one must zero-in onto areas of identified concern, even if the building's performance in general is quite good. This raises the point that there is always room for improvement in order for the building to run even more efficiently, despite high standards and targets that were met, and hence further bridging the credibility gap in the performance of non domestic buildings in general.

4.4.2 Building Occupant Survey – Adrian Leaman [26]

Conducted in November 2006, Leaman's occupant survey aimed at providing feedback from occupants that is relevant to the building design and ongoing building management. His report includes an overview of how well the building compared with a benchmark set of 60 buildings around the world, which like the Heelis, are "low energy, green" buildings in their design intent. In his survey, questionnaires were given out to members of staff, where the total sample size reached 242, with a response rate of 92%. The following points summarize some of the main findings [26]:

- The building performs very well on soft variables like design, occupants' needs, image as well as forgiveness of occupants.
- The Heelis ranks within the top percentiles on perceived health
- The quality and quantity and quantity of daylight and artificial lighting scored well
- Although a deep plan building is accepted as a difficult building type to satisfy occupants, Heelis scores well in this category
- The perceived productivity, which is closely related to thermal comfort, temperature and perceived control, is positive
- Productivity in the building is significantly affected by occupant density

In his survey, Leaman addresses a number of environmental conditions that affect thermal comfort in addition to addressing the needs of the occupants with respect to the physical environment, including facilities like storage space. The summary chart in figure (4.23) shows the results for the different variables that were addressed in the survey. The green triangles represent mean values that are significantly better or higher than both the benchmark and scale midpoint. Amber circles represent mean values that are no different from benchmarks while red diamonds indicate mean values that are worse or lower than benchmark and scale midpoints. Benchmarks for the UK are represented by the white lines.

Figure (4.23):
Results of the Heelis occupant survey conducted by Building Use Studies (BUS) in 2006 for each of the variables, *Source [26]*

The survey indicates that around 68% of staff believes that their productivity is either not affected or not improved by the building, a relatively good result as it is above the benchmark UK mean for perceived productivity. As previously mentioned, the building scores well for design, occupant needs, space and lighting; on the other hand, its lowest scores include perceived control, noise, temperature and air. The lack of control of heating, lighting levels and acoustics in addition to background noise affect comfort levels. In addition, occupants seem to find the building too hot during the summer and too cold during the winter according to the results.

Examining the categories where the Heelis does not perform as well as anticipated in further detail shows a number of prominent findings, mainly related to temperature, air quality, noise and control. These include the following [26]:

- Just over half the staff (51%) thinks that it is reasonably comfortable during the winter time but temperatures can be too cold according to 47% them. Winter conditions are also perceived as variable. Furthermore, the intolerance of occupants in general to automatic devices that lack overrides that they can use, or their inability to understand the need for the device to operate affects perceived levels of comfort, particularly during colder periods.

- Over half of the staff (52%) are uncomfortable during the summer, with the majority feeling too hot. As it is the case in winter, temperatures are perceived as variable, which results in some occupants feeling too cold as well.
- Although most occupants believe that ventilation conditions in winter are reasonably good, with 39% saying that it is too draughty, around 45% of occupants say that conditions are unsatisfactory during summer. A higher than usual proportion of staff commented positively on the comfort conditions in general though, showing a wide range of response in this category in particular between winter and summer conditions.
- There are marked comfort differences between floors, where staff indicate that the first floor is more comfortable than the ground floor. Moreover, those with window seat on the first floor are more comfortable.
- 45% of the staff say they suffer from interruptions due to noise. The large proportion is indicative of a problem for a building of this sort, despite the fact that its overall noise score is reasonable for a deep, open plan office building. The ground floor is also found to be noisier than the first, with the central areas being the noisiest.
- The scores for perceived scores for lighting and noise are lowest in comparison to ventilation, heating and cooling which are a little better. This in itself is unusual, as heating and ventilation control scores are normally the lowest, and lighting the best. 20% of staff says that control over the aforementioned factors is important to them, with noise control rated slightly less important (15%). Perceived control is more vital in situations where environmental conditions are perceived to be poor. In this case however, the relative lack of control is probably not so much of an issue as it might be in other building that are more "close-control".

A summary of occupant perceptions for all conditions and factors at the Heelis can be found in table (4.6).

Condition	Occupant survey result
Temperature in winter	Reasonably comfortable overall, but too cold in winter
Temperature in summer	Too hot and variable in summer, uncomfortable overall
Air in winter	Most ratings reasonably good and close to benchmark, smellier in winter
Air in summer	Reasonably good, but possibly too still
Lighting	Reasonably good rating overall. Good ratings for natural light and artificial light, low glare both from sky and from lights
Noise	All noise ratings either same as or worse

	than benchmarks. Random noise from sources other than colleagues worse
Perceived control	All perceived control variables are below benchmark. The highest rating is for control over ventilation
Image	A good score, the benchmark is very high
Cleaning	Similarly, a reasonably good score with a high benchmark
Furniture	Close to benchmark
Meeting rooms	Close to benchmark
Space at desk	About right
Space in the building	A good rating
Storage	Close to the scale mid-point
Health	A reasonably good score above the benchmark
Facilities meeting needs	A good score with a high benchmark
Perceived productivity	Marginally positive, a reasonably good score for a large building

Table (4.6):
Summary of occupant perceptions for all conditions and factors at the Heelis, *Source [26]*

In his report, Adrian Leaman outlines the results that place the Heelis in the top 40^{th} percentile in the BUS dataset for international buildings and among first among similar buildings in the UK. According to him however, this is a somewhat "disappointing outcome, especially given the building's award winning credentials". The main reasons for this are ratings for thermal comfort and noise, in addition to the fact that larger buildings are disliked more by occupants in general, not matter how well they are designed. According to Leaman, buildings with the highest occupant ratings tend to be:

- Thermally comfortable with low distractions from noise;
- Respond quickly to occupants' desire to make changes via user controls;
- With a shallow plan with a high proportion of window seats and views to the outside;
- Relatively simple to manage;
- With well-defined workgroups and circulation spaces.

He further outlines that one of the most notable aspects about the building is how much occupants "like" the building and are willing to tolerate some of its perceived faults. This is due to their understanding of design intent, backed by the building's image as a whole.

Perhaps one of the most important aspects about Leaman's study is that it enables one to go beyond the figures, percentages and results, to realize the importance of post occupancy review as tool to asses he building's performance. Unlike examining the pure logistics of how the building works and how much energy it consumes and inherently the CO2 emissions it produces, this approach brings together the occupants and the building fabric at a much more "intimate" level, where they get to experience first hand the effects of the buildings successes and shortcomings.

A particularly powerful characteristic of this study is the amount of detail and variety that the occupant is faced with at the questionnaire level. It brings together both the physical characteristics of the building's design simultaneously with environmental conditions and other related issues like transport for example. By doing this, it is easier to adopt a more holistic approach to process of post occupancy evaluation. Only by doing this, can one be able to understand the interrelationships between the natural and man made environments and how those are affected and changed by entering into a building's occupancy stage in its life cycle.

Furthermore, Leaman clearly states that although the building is "an outstanding building of its type"; there is room for further improvements that would help develop perceptions of workplace productivity in general. By doing this, he is again placing the building in the context of what happens after its occupancy and how things can be improved during this particular stage. The comparisons drawn in the report between the Heelis and other similar exemplary buildings are also useful in order for one to think about the next step and what can be done to improve the performance of not only the Heelis, but office buildings in general.

4.4.3 Review of energy use, ventilation and heating plant performance in 2006 [27]

In addition to post occupancy reviews conducted by Bordass and Leaman, an assessment of the energy use in the building was undertaken by the engineers at Max Fordham, as part of their on going process to monitor the building's performance. As the summer of 2006, particularly the month of July, was an exceptionally warm period in the UK, temperatures during July were monitored in order to see how well it would avoid overheating. The mean temperature value for the month was 19°C, which is 3.6°C above the 1961-1990 average. Moreover, the average mean temperature for 2006 was 1°C higher than that of 1997.

It was found however, that despite all this, the building managed to remain within the limits set during the design. Table (4.7) and figure (4.24) illustrate the percentage of working hours that exceed the standards set by BRE in their guide "Energy Efficient Office of the Future"[††] for the Heelis during the month of July, 2006. A breakdown of temperatures for each floor, given in further detail for the entire year in the pie charts that follow, shows that the ground floor performed better than the first, a result which can be expected because of the open nature of the building's interior space.

Category	Ground Floor	First Floor
% of working hours where temperature exceeds 25˚C	2.7	4.31
% of working hours where temperature exceeds 28˚C	0.14	0.62

Table (4.7):
Percentage of monitored working hours that exceed design limits during July, 2006, Source [27]

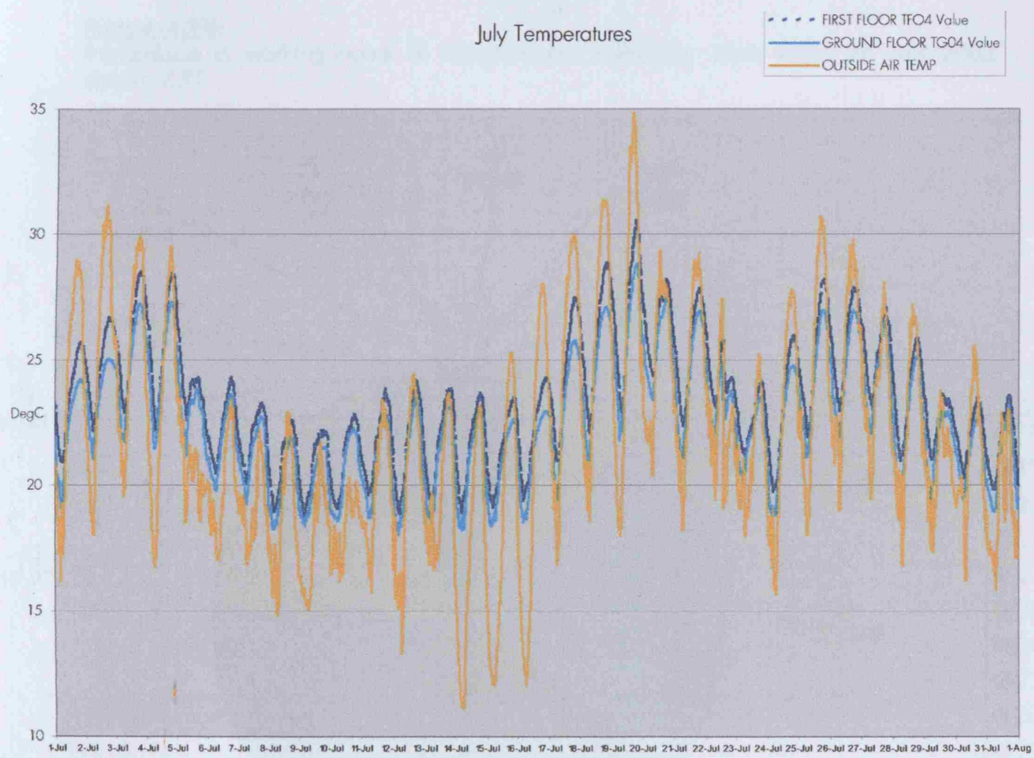


Figure (4.24):
Results for internal temperatures for both floors in comparison to the external temperature for the month of July, 2006, *Source [27]*

[††] It states that the internal dry resultant temperature should not exceed 25°C for more than 5% of working hours and should not exceed 28°C for more than 1% of working hours.

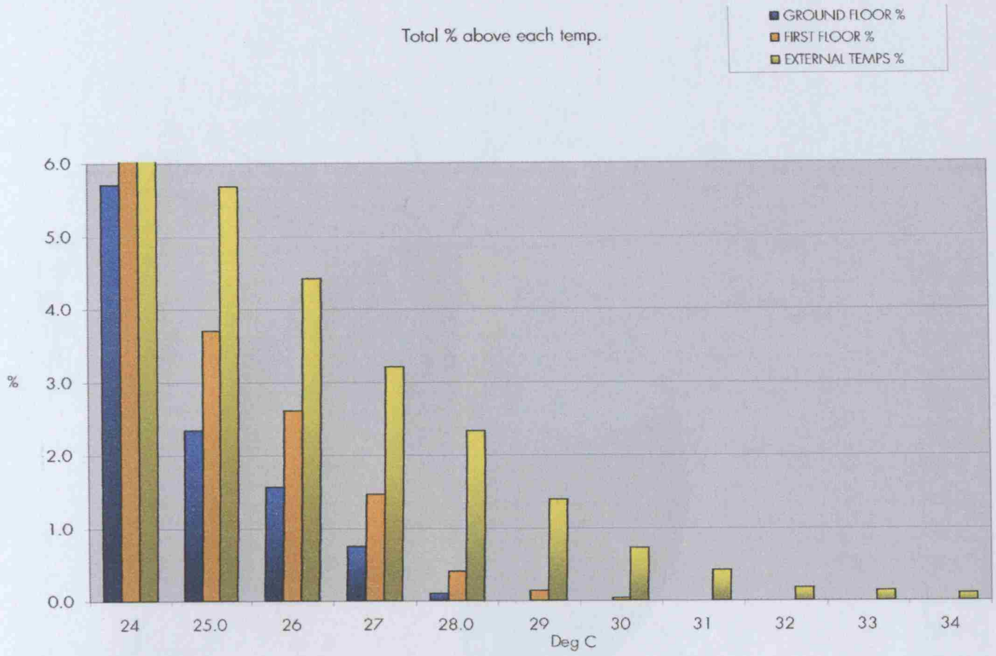


Figure (4.25):
Percentage of working hours of temperatures exceeding each value for July 2006, ***Source [27]***

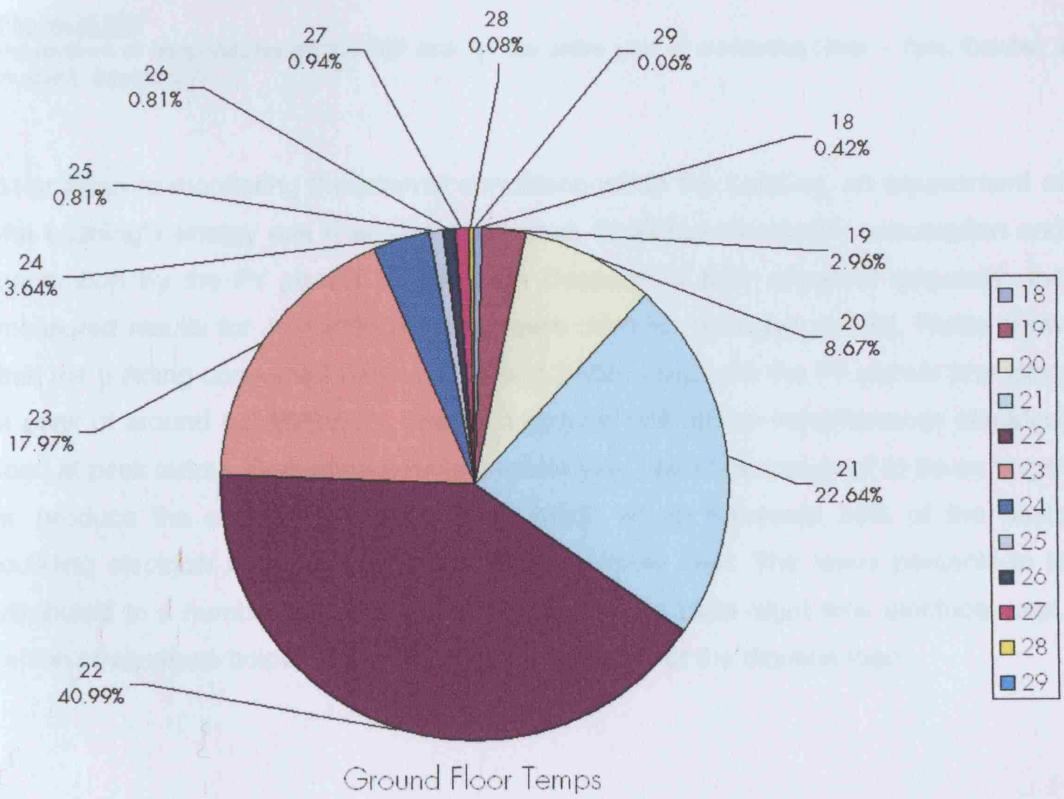
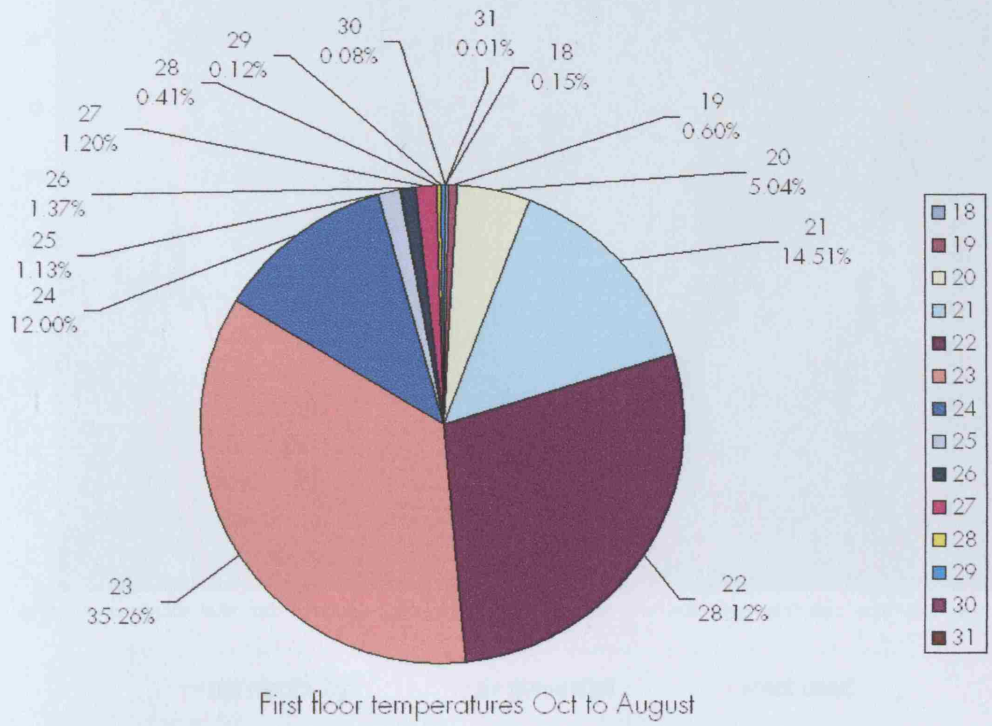


Figure (4.26):
Breakdown of temperatures on the ground floor for the entire year of monitoring (7am – 7pm, October to August), ***Source [27]***



<u>Figure (4.27)</u>:
Breakdown of temperatures on the first floor for the entire year of monitoring (7am – 7pm, October to August), *Source [27]*

In addition to monitoring the internal conditions within the building, an assessment of the building's energy use was also conducted, including electricity consumption and generation by the PV panels on the roof. Because of their apparent accuracy, the measured results for July 2006 onwards were used for electrical meters. These show that the building consumed between 1.5 and 2 MWh/day, with the PV panels providing a peak of around 0.5 MWh/day. The PV's provide 60% of the instantaneous electrical load at peak output. Furthermore, over a whole year, the PV's appeared to be on target to produce the anticipated 90-100 MWh which would represent 30% of the basic building electrical load or 10% of the total electricity load. The lower percentage is attributed to a number of factors, one of which is the base night time electrical load, which rarely drops below 60 kW, an equivalent to 50% of the daytime load.

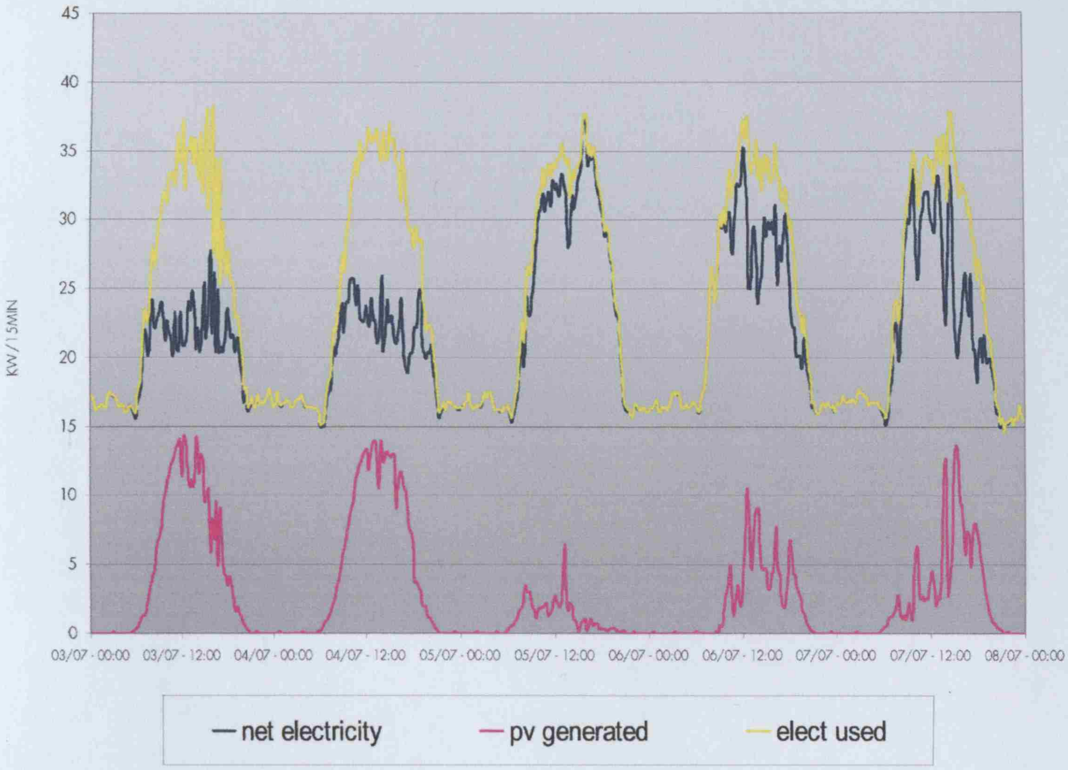
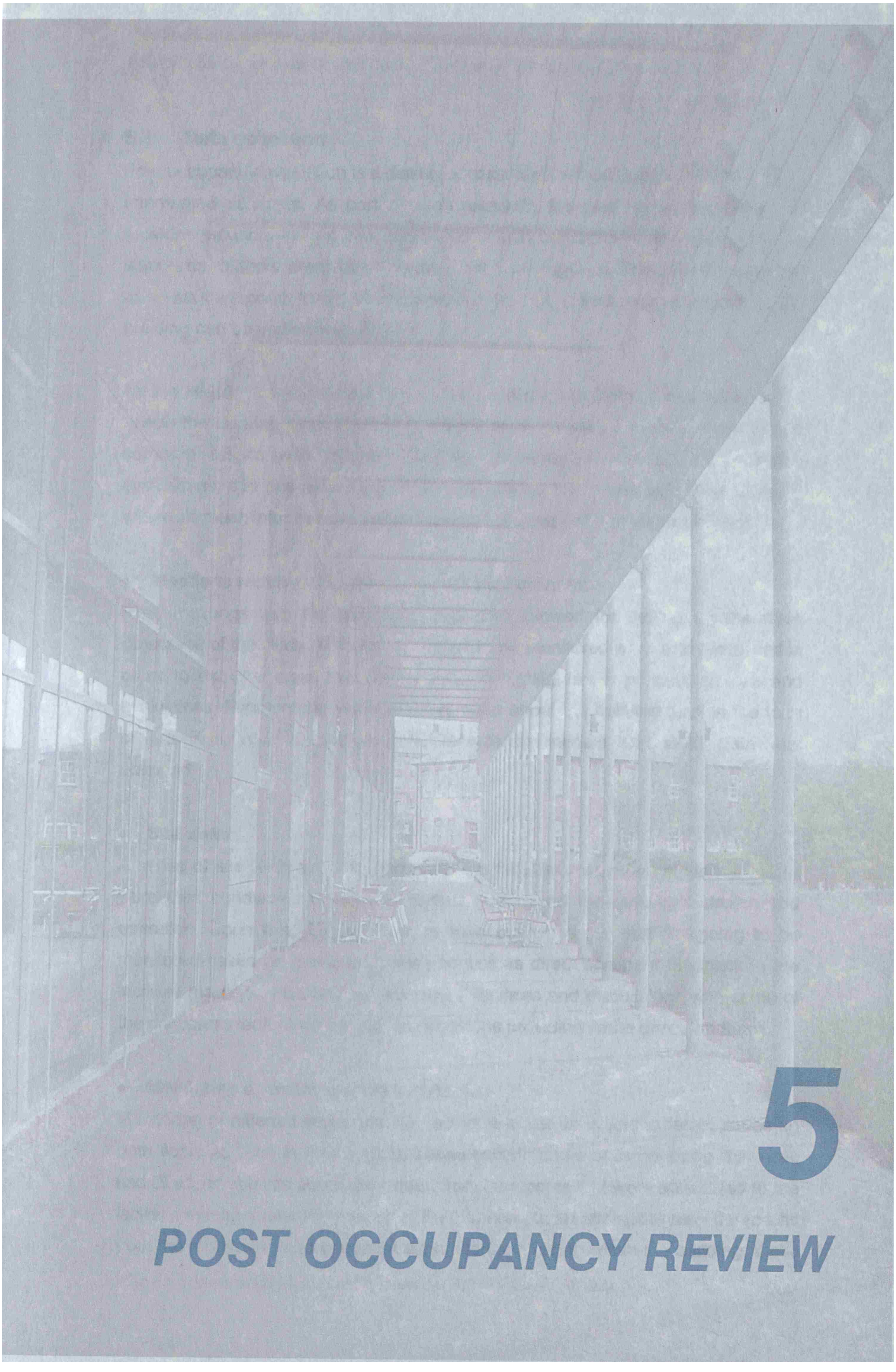


Figure (4.28):
Electricity used and consumed during early July 2006, including the amount generated by PV's, net electricity and electricity used, *Source [27]*

Moreover, the lighting load of the building seemed to contribute to the lower percentage. While no accurate measurements were possible, an analysis of the probable plant load showed that the annual electrical consumption of the lighting is around 22kWh/yr/m². This is comparable to ECON 19 good practice but 3 times more than what was expected. This is due to the failure of the lighting control system to switch the lighting off when it is not required. Figure (4.28) shows the electricity generated and consumed at Heelis during early July 2006. The same pattern for net electricity, electricity used and that generated by PV's is repeated throughout the year, where the electricity generated by PV is the only variable factor. In general, the night time electrical load is found to be 60 kWh and the daily working hours load and the peak PV generation are 120-140 kWh and 56 kWh respectively.



5

POST OCCUPANCY REVIEW

5.1 Data collection

Post occupancy evaluation is a distinct assessment method that incorporates many interrelated variables. As part of such research, the process of data collection provides valuable insight into comparisons with benchmarks and good practice standards to show areas of compliance and convergence. This may be regarded as a starting point from which assessing the full environmental impact of the building can be undertaken [28].

As the Heelis was the subject of 2 previous studies in 2006, it was important to review the building again in order to assess its performance over the summer and compare results with previous findings. However, in contrast to preceding evaluations, this one examines comfort conditions in 4 areas within the building, where as much information as possible was obtained through various means.

- **Meetings with building engineers at Max Fordham:**

First, meetings with the building's engineers allowed for setting up the main objectives of the study. The main variables to be monitored were also discussed in order to examine areas that have not been highlighted in previous studies and evaluations. Furthermore, valuable information about the building itself in the form of drawings, reports, presentations, simulation models and BMS data was obtained.

- **Site visits:**

A series of site visits and meetings with the facilities management staff at Heelis were then conducted in order to further understand the building's design and operation. Upon this, it was easier to map out the areas that are going to be monitored based on previous reviews as well as direct occupant feedback to the facilities manager. Furthermore, informal interviews and discussions with some of the occupants took place on various occasions providing some direct feedback.

- **Monitoring of environmental conditions:**

Monitoring of different environmental factors was set up in four different zones on both floors as seen in Figure (5.1). These include areas of the building that have had direct complaints about discomfort from occupants that were addressed to the facilities manager over the past year. Furthermore, in an attempt to map the results from the monitoring and occupant survey to the location within the building, these zones have been chosen to form comparisons and provide a more manageable pool of data for analysis.

Data loggers were used to measure temperature and relative humidity (RH) while modified HOBO's were used as globe thermometers to measure radiant temperature. This is of particular interest as radiant temperature, and subsequently dry resultant temperature (DRT) is a more direct indicator of thermal comfort, and has not been monitored in this building before. As the building engineers have voiced some concern about the air temperature in the courtyards, which is the supply for adjacent zones within the building, data loggers were also placed in both courtyards to measure the external temperature and RH. In addition, air velocity and daylight factors were recorded for each of the four zones, where the latter was used to complement the comfort survey rather than form a comprehensive daylight study that was not possible within the scope of this project.

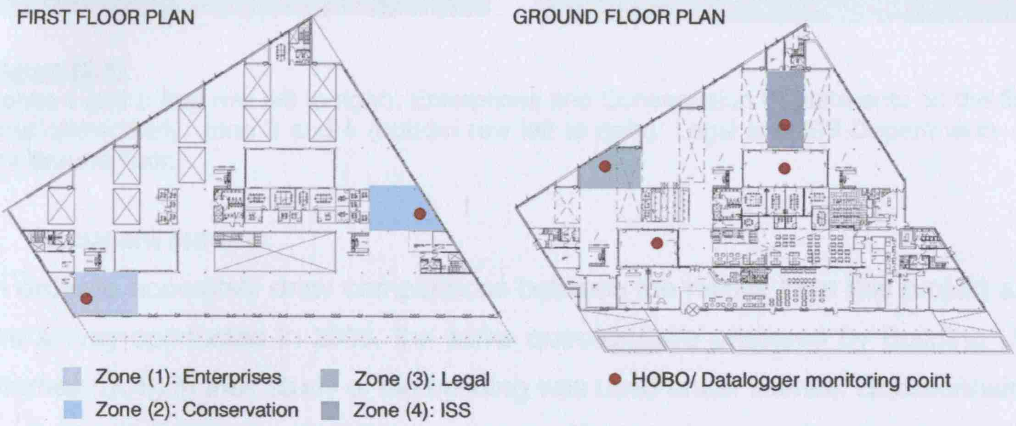


Figure (5.1):
Monitoring points and zones at Heelis: Zones 1 and 2 on the first floor to the south west and east respectively, and zones 3 and 4 on the ground floor to the west and north east respectively

Figure (5.2):
Zones 1 and 2 (top row left to right): Enterprises and Conservation Departments on the first floor respectively, zone 3 and 4 (bottom row left to right): Legal and ISS Departments on the ground floor.

- **Occupant survey:**

In order to accurately draw comparisons between the results from this project and the survey conducted in 2006, the same questionnaire prepared by Building Use Studies (BUS) in their study of the building was used under license. Questionnaires were distributed by hand to the occupants within the four monitored zones in the morning and collected on the same day in the afternoon.

The survey covers a wide array of issues related to the office environment and include in addition to environmental factors, the design of the building, perceived health, comfort, productivity, control and information regarding transport to and from work. Moreover, the questionnaire allowed occupants to present more detailed responses in the form of additional comments to the questions, providing further insight into occupants' opinions and the way they interact with their environment. The results from the survey are analyzed in more detail in the following section.

5.2 Occupant survey analysis

The occupant survey represents the core of the project, as it is the main tool to provide data about comfort conditions in the building. For the purposes of this study, a sample of 100 questionnaires were distributed in the aforementioned zones in order to map the results across the building floor plate and examine the differences between various locations within the building (east, west, north and south) on both floors. The sample returned a response rate of 82%.

The same questionnaire format as that conducted in 2006 was used, with a rating scale for each question ranging from 1 to 7. Table (5.1) shows the meaning of the abbreviations used in some of the figures and main survey results that follow. Full results for each category can be found in Appendix 8.5.

Variable	Abbreviation
Comfort	
Overall comfort	COMFOVER
Overall temperature in winter	TWOVER
Overall temperature in summer	TSOVER
Overall winter air quality	AIRWOVER
Overall summer air quality	AIRSOVER
Lighting overall	LTOVER
Noise overall	NSEOVER
Temperature	
Temperature in winter	TWHOT
Temperature in summer	TSHOT
Air	
Air quality in winter	AIRWFRESH
Air speed in winter	AIRWSTIL
Air quality in summer	AIRSFRESH
Air speed in summer	AIRSSTIL
Lighting	
Natural lighting	LTNAT
Artificial lighting	LTART
Control	
Control over heating	CNTHT
Control over cooling	CNTCO
Control over ventilation	CNTVT
Control over lighting	CNTLT
Productivity and health	
Productivity	PROD

Table (5.1): Survey variables and their abbreviations that were used in the occupant survey

Overall, there is a slight improvement in comfort conditions with many of the variables scoring above benchmark values and marking an improvement from 2006 results. Figure (5.4) shows a summary of the results for the main categories. Overall comfort scored significantly higher than both benchmark and scale midpoint, placing it in the 82nd percentile of the BUS database of surveyed buildings with a mean score of 5.23 (see figure 5.3). There are also improvements in both overall winter and summer temperatures, scoring close to and significantly higher than benchmark values respectively.

Furthermore, results for air quality scored significantly higher than scale midpoints and benchmark values for both winter and summer with a mean of 4.34 and 4.21 respectively. As for lighting, overall lighting conditions are significantly higher than both benchmark values and the scale midpoint. The same applies to the score for natural lighting. However, artificial lighting had a score that is not different from scale midpoint but significantly, lower than the benchmark value for the BUS database, which uses UK benchmarks for this study as opposed to the international benchmarks used in the previous study.

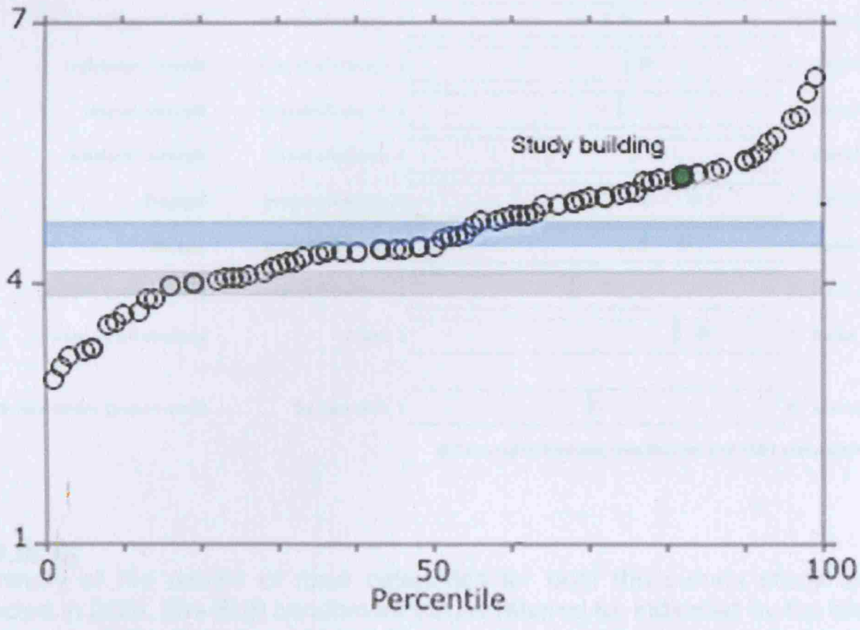
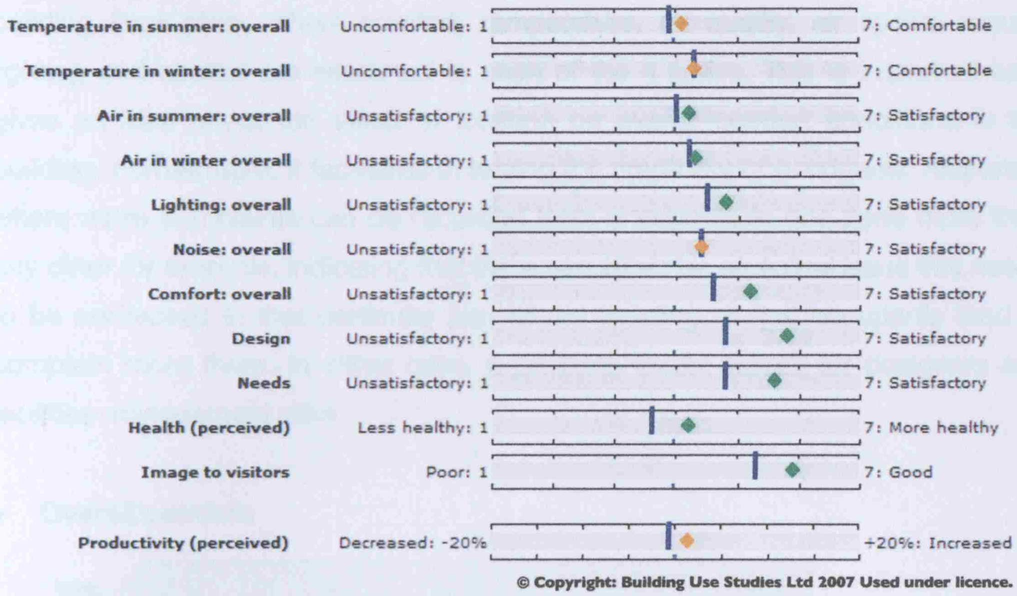


Figure (5.3):
The BUS index overall comfort score for Heelis within the database. The grey band represents the scale midpoint for score for overall comfort (1 being unsatisfactory and 7 being satisfactory). The blue band represents the benchmark UK value, where Heelis is ranked in the 82nd percentile among all the buildings in the database.

2007 STUDY



2006 STUDY

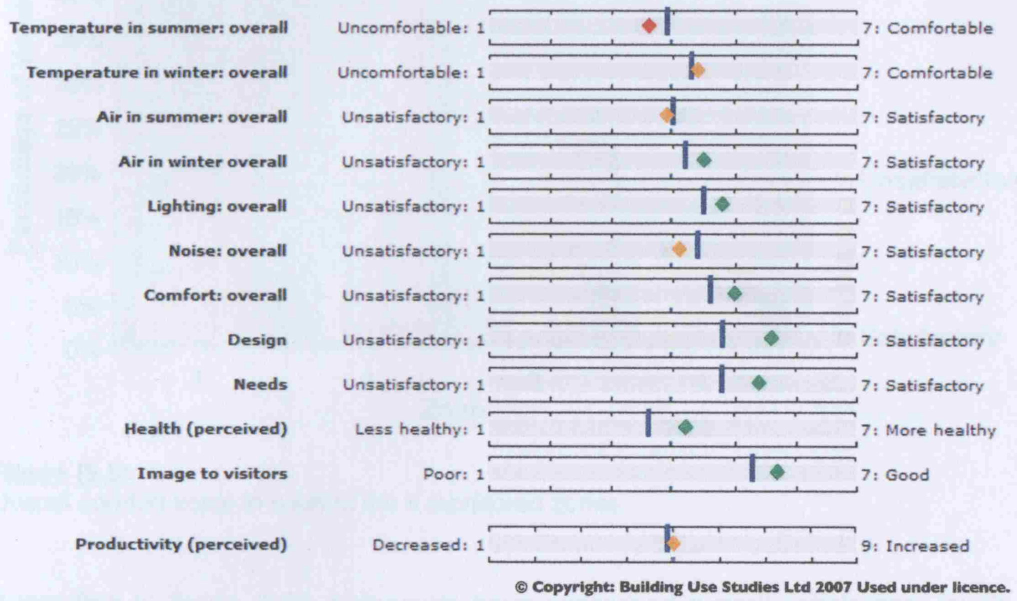


Figure (5.4):
A summary of the results of main categories for both the current study and that conducted in 2006. The BUS benchmark values referred to, indicated by the blue lines through each scale, including UK buildings for the current study and an international database for the previous one. The green diamonds represent mean values significantly better or higher than both the benchmark and scale midpoint. Amber diamonds are mean values no different from benchmark. Red diamonds are mean values worse or lower than benchmark and scale midpoint.
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The following figures show the mapping of survey results over various parts of the building floor plate, where comfort, temperature, air quality, air speed, natural lighting and control are examined in each of the 4 zones. This is important as it gives an idea about the effect of location on overall comfort conditions in the building. Furthermore, it facilitates in testing the credibility of occupants' response, where more complaints can be recorded from occupants in one zone more than any other for example, indicating that there can either be an actual issue that needs to be addressed in that particular part of the building or that occupants tend to complain more there. In either case, it provides useful insight for designers and facilities management alike.

- **Overall comfort:**

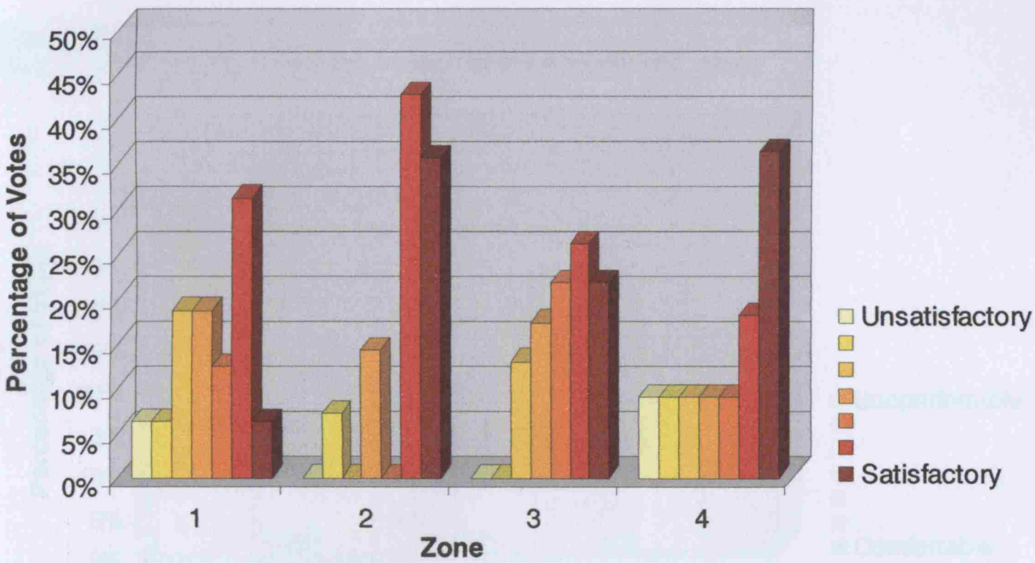


Figure (5.5):
Overall comfort votes in each of the 4 monitored zones.

According to figure (5.5), occupants have expressed overall satisfactory levels of comfort in all of the monitored zones, with occupants in Zones (2) and (4) on the first and ground floor respectively being the most satisfied with 42.9% and 36.4% of the votes respectively. This shows that, while it might have a bigger impact on detailed variables that affect comfort, location in the building plays a minor role on occupants' general perception of comfort that takes into account all of the factors together.

- **Overall Temperature**:

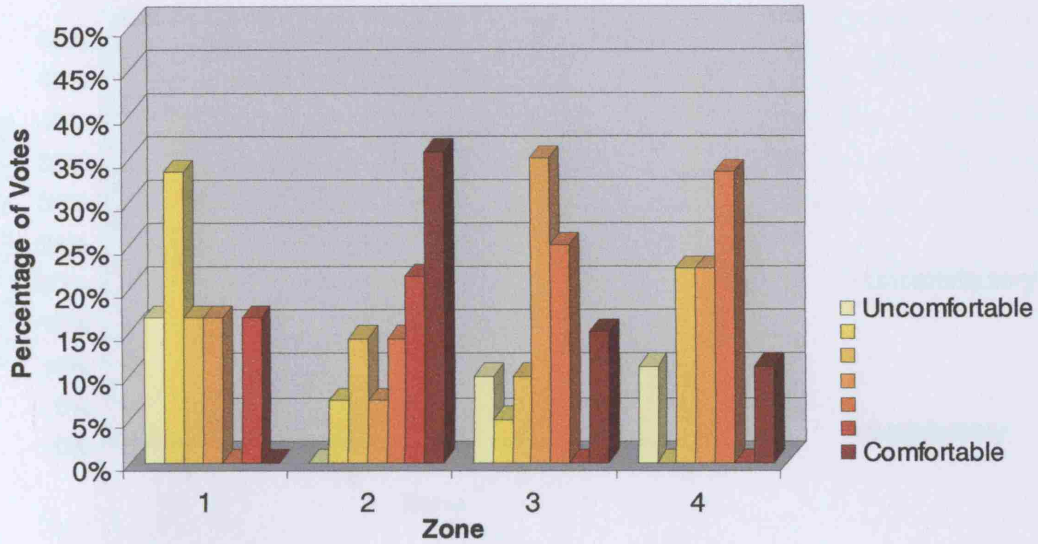


Figure (5.6):
Overall winter temperature votes in each of the 4 monitored zones

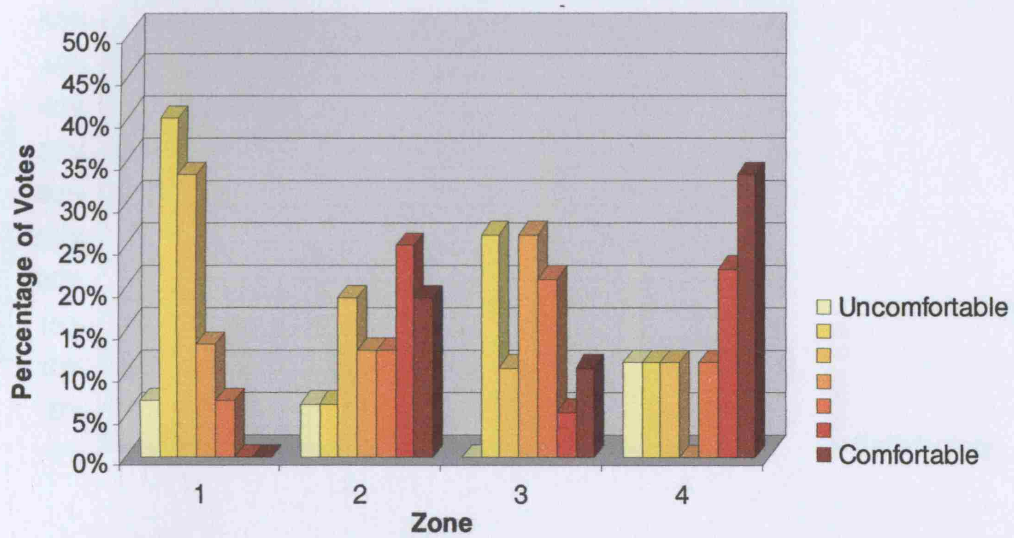


Figure (5.7):
Overall summer temperature votes in each of the 4 monitored zones

Although overall comfort votes in all of the 4 zones are more towards the satisfactory end of the spectrum, figures (5.6) and (5.7) indicate that this is not particularly true with regards to temperature in winter and summer. Zone (1) in both cases exhibits the highest levels of discomfort, with up to 40% and 33.3% expressing discomfort for summer and winter temperatures respectively. On the other hand, occupants in zone 2 find winter temperatures to be the most comfortable with up to 35.7% of the votes, while up to 33.3% find summer temperatures most comfortable in zone 4.

- **Overall Air:**

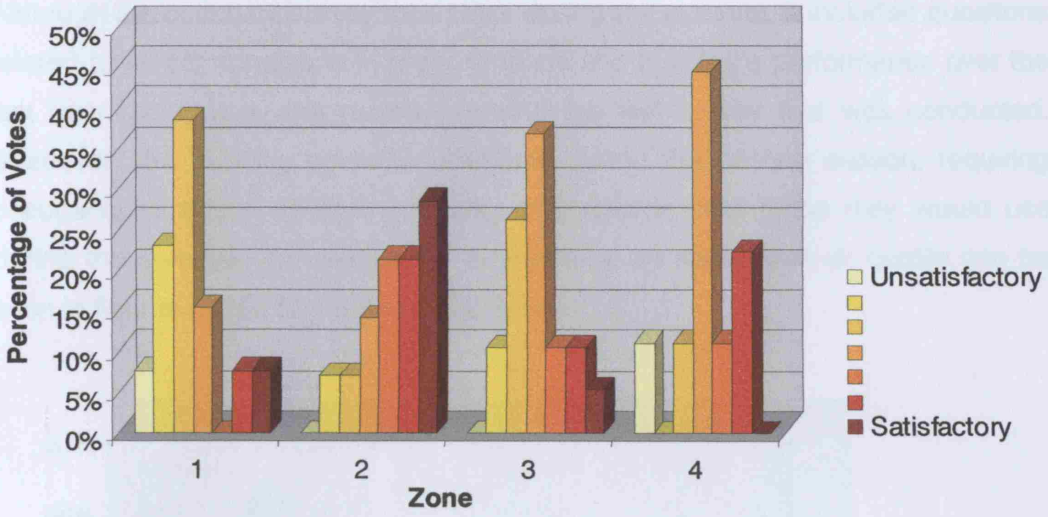


Figure (5.8):
Overall winter air votes in each of the 4 monitored zones

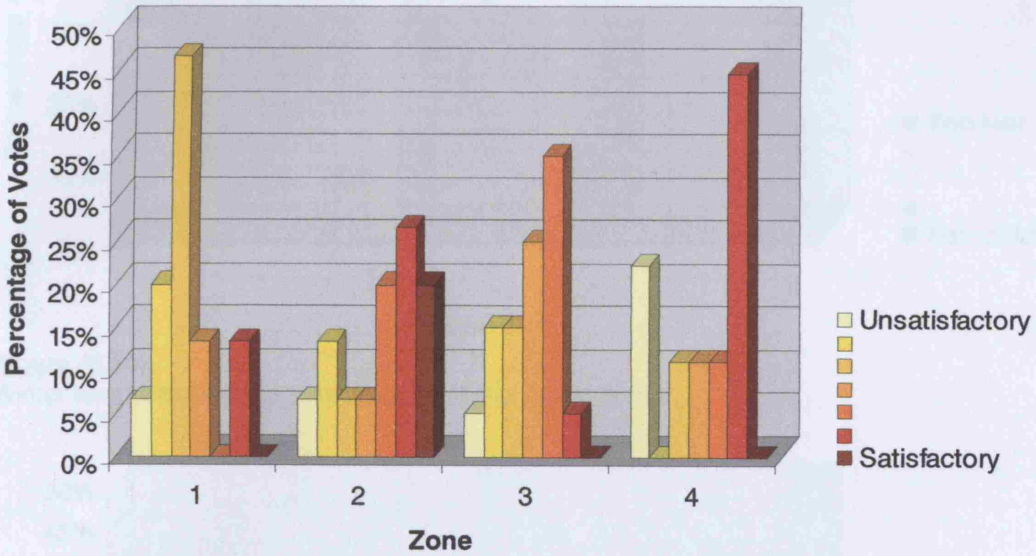


Figure (5.9):
Overall summer air votes in each of the 4 monitored zones

Overall air as a category takes into account air quality, speed, humidity and smell. According to figures (5.8) and (5.9), conditions in zones 2, 3 and 4 are satisfactory for both winter and summer conditions, with the votes closer to scale midpoint for winter. Again, zone 1 on the first floor shows lower levels of satisfaction than other parts of the building, with 38.5% and up to 46.7% of the votes for winter and summer respectively.

- **Winter Comfort Conditions:**

Although the occupant survey took place during the summer, it included questions related to winter conditions in order to follow the building's performance over the last year, particularly the period following the last survey that was conducted. Moreover, the building operates differently during the heating season, requiring occupants to adopt different adapting mechanisms than those they would use during the summer. The results for temperature, air speed and air quality can be seen in figures (5.10), (5.11) and (5.12) below.

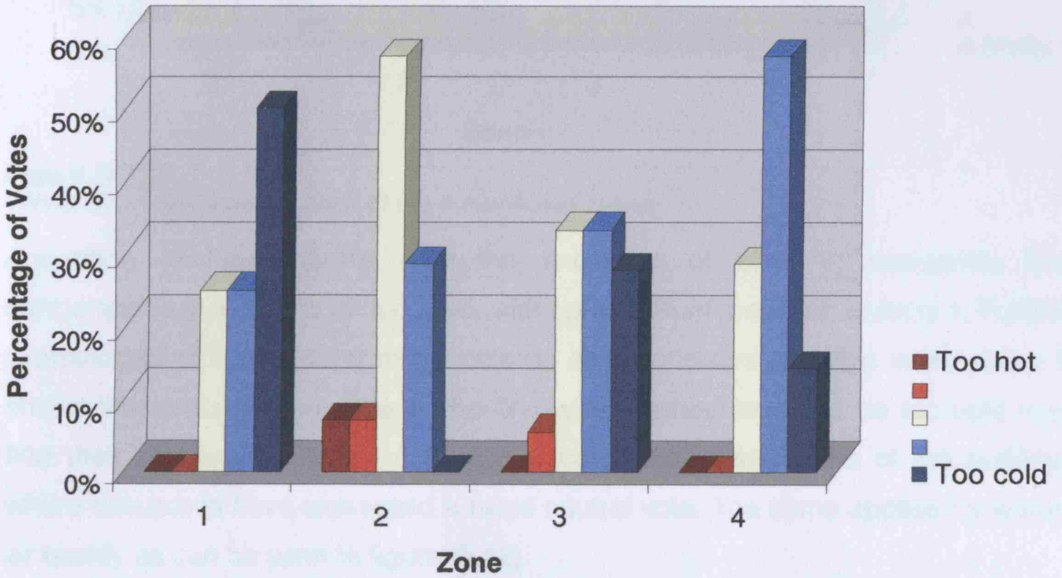


Figure (5.10):
Winter temperature votes in each of the 4 monitored zones

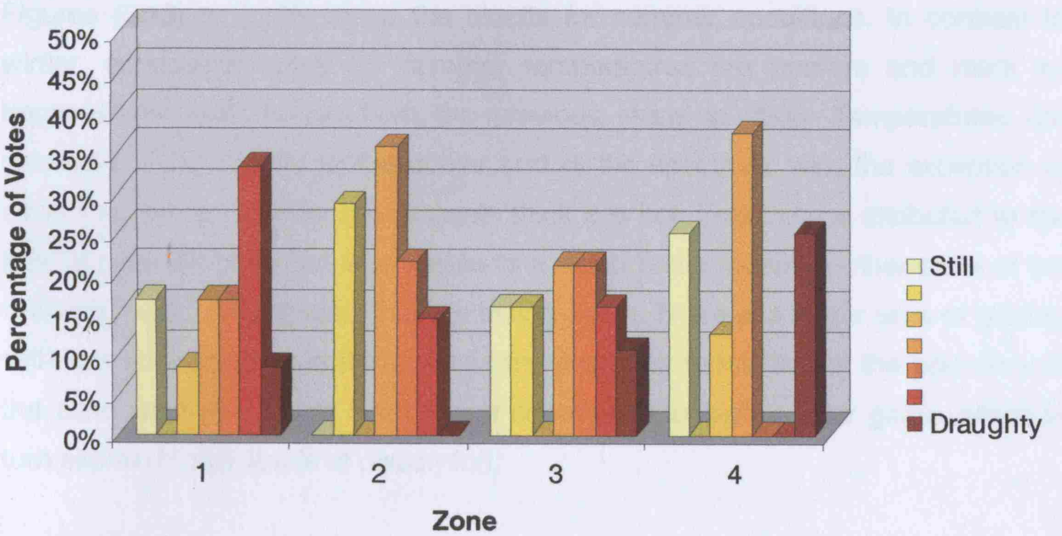


Figure (5.11):
Winter air speed votes in each of the 4 monitored zones

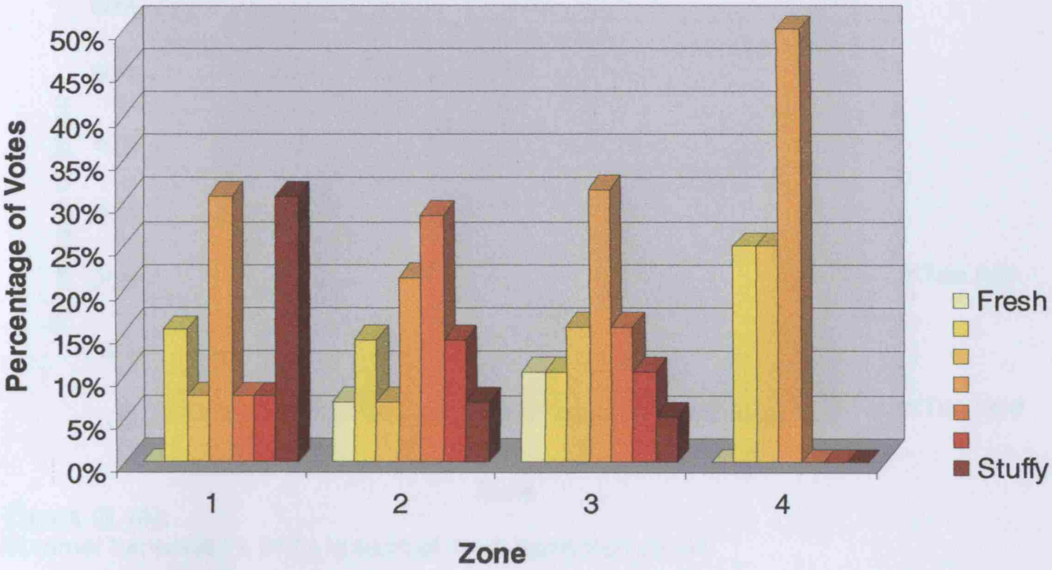


Figure (5.12):
Winter air quality votes in each of the 4 monitored zones

According to figure (5.10), with the exception of zone 2, occupants find temperatures in winter to be too cold, with up to 50% of the votes in zone 1. Further examination of figure (5.11) might provide some answers why this is the case. It shows that occupants in zone 1 who find winter temperatures to be too cold also find their environment to be draughty in contrast to other parts of the building where occupants have expressed a more neutral vote. The same applies for winter air quality as can be seen in figure (5.12).

- **Summer Comfort Conditions:**

Figures (5.13) to (5.15) show the results for summer conditions. In contrast to winter, occupants' votes for summer temperatures are positive and mark an improvement over results from the previous study in 2006. Temperatures are generally in the neutral to the cooler end of the spectrum, with the exception of zone 1 where up to 40% of occupants think it is hot. This can be attributed to the lack of solar shading that is available to a much better extent in other parts of the building, particularly spaces that are facing south. There is a larger area of glazing with less solar shading in this zone as the overhang terminates at the boundary of the zone itself (see figure 5.16) which contributes to higher solar gains, which in turn explain higher levels of discomfort.

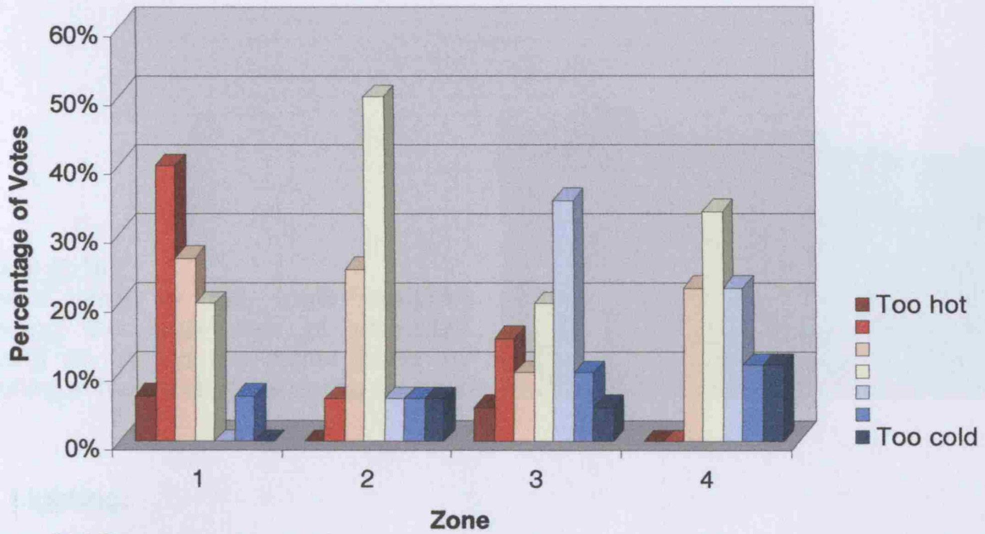


Figure (5.13):
Summer temperature votes in each of the 4 monitored zones

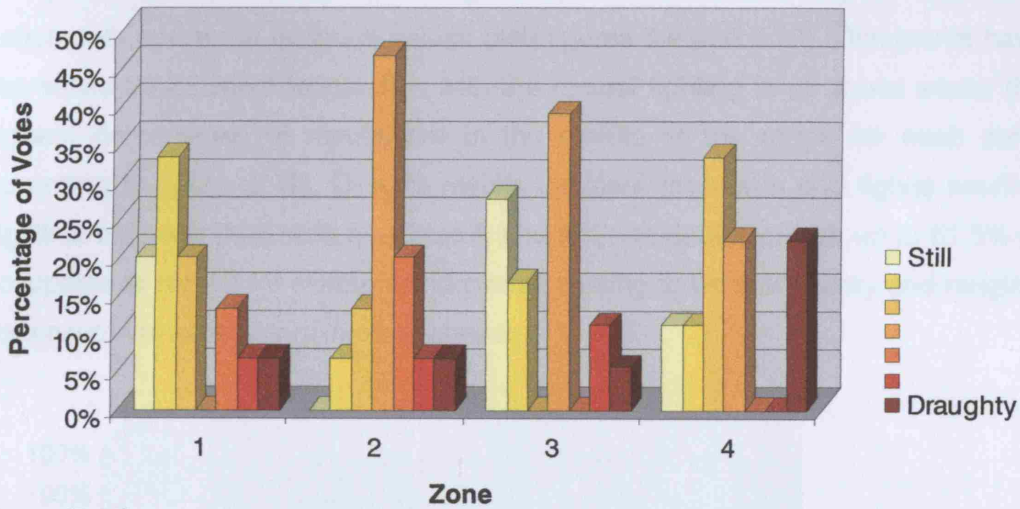


Figure (5.14):
Summer air speed votes in each of the 4 monitored zones

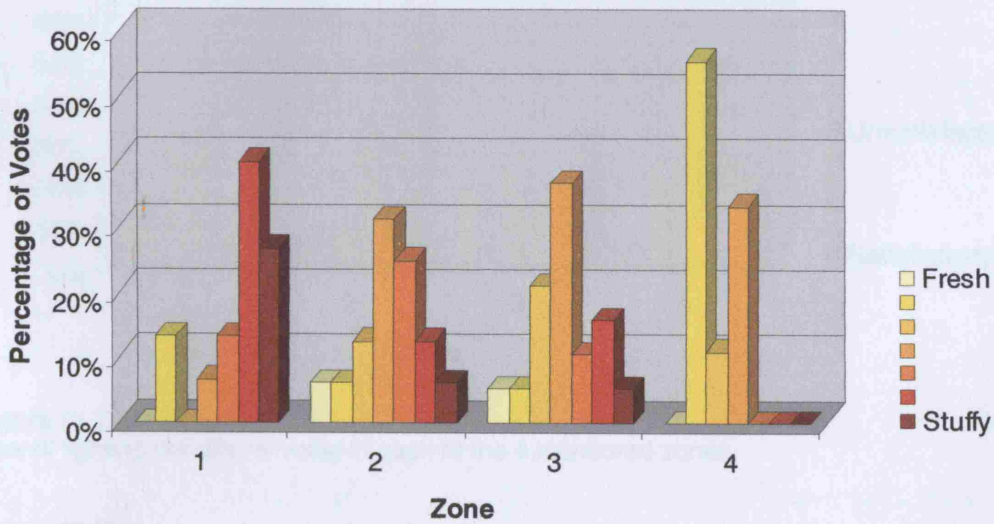


Figure (5.15):
Summer air quality votes in each of the 4 monitored zones

Figure (5.16):
Exterior view of the south elevation showing the large area of unshaded glazing at the top left corner (zone 1), resulting in high solar gains during summer

- **Lighting:**

The results for overall lighting conditions and natural lighting are shown in figures (5.17) and (5.18) respectively. In general, the results are higher than both benchmark and scale midpoint values (see figures 5.4 and 5.23). Occupants have expressed their overall satisfaction with the natural lighting in all zones where the highest percentages of results are in the middle of the range for each zone according to figure (5.18). Despite results for glare (from sun and lights) scoring significantly lower than both benchmark and scale midpoint values, up to 61.5% of occupants in zone 2 for example find overall lighting to be satisfactory and ranging from neutral to satisfactory in other zones.

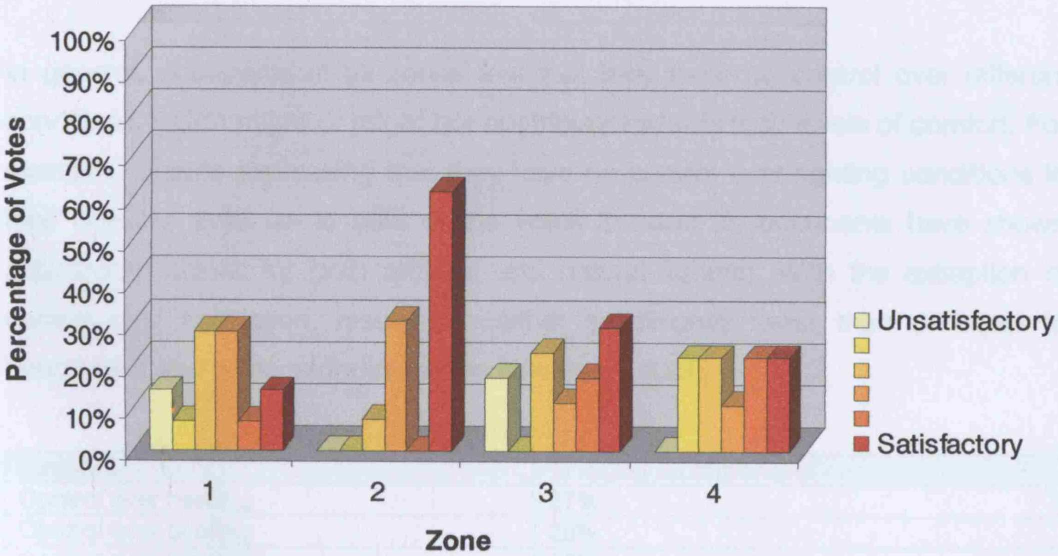


Figure (5.17):
Overall lighting conditions votes in each of the 4 monitored zones

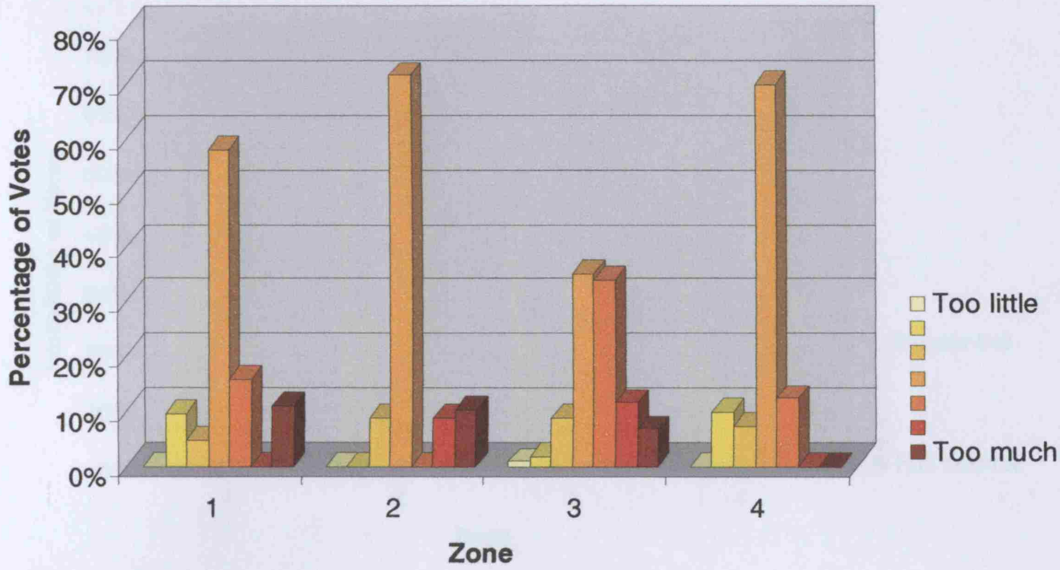


Figure (5.18):
Natural lighting votes in each of the 4 monitored zones

- **Control:**

In naturally ventilated buildings, perceived control levels can often provide some insight into occupants' dissatisfaction with some of the comfort conditions in their building. Figures (5.19) to (5.22) show the results for perceived control over a number of variables including heating, cooling, lighting and ventilation. Table (5.2) shows the percent ratings as important for each variable.

In general, occupants in all zones feel that they have no control over different conditions, which might or might not contribute towards their levels of comfort. For example, despite expressing that they have no control over lighting conditions in their building (with up to 59% of the votes in zone 3), occupants have shown satisfactory results for both artificial and natural lighting. With the exception of control over ventilation, results are either significantly lower than or equal to benchmark and scale midpoint values (see figure 5.23).

Variable	% rating as important
Control over heating	27%
Control over cooling	26%
Control over lighting	16%
Control over ventilation	36%

Table (5.2):
Survey results for percentage rating of perceived control being important to occupants in all zones

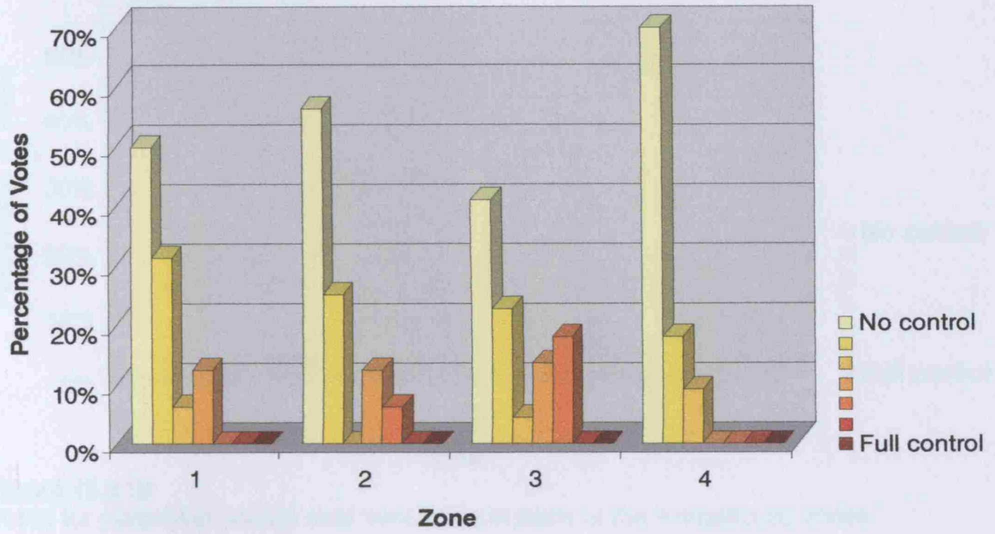


Figure (5.19):
Votes for perceived control over heating in each of the 4 monitored zones

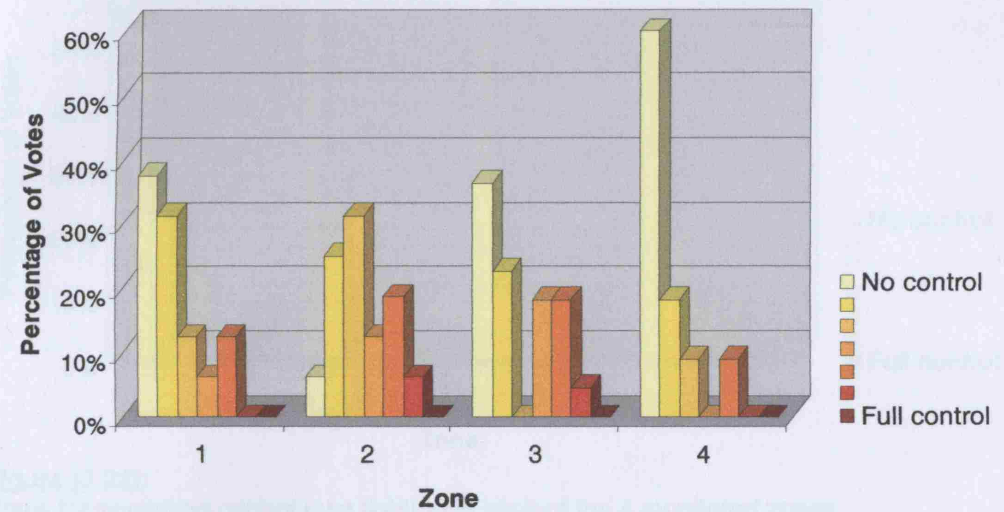


Figure (5.20):
Votes for perceived control over cooling in each of the 4 monitored zones

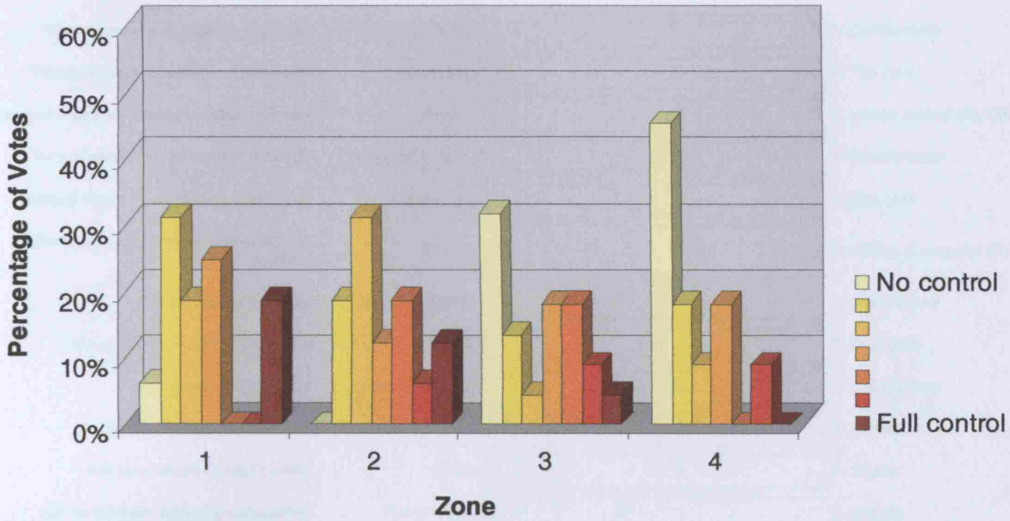


Figure (5.21):
Votes for perceived control over ventilation in each of the 4 monitored zones

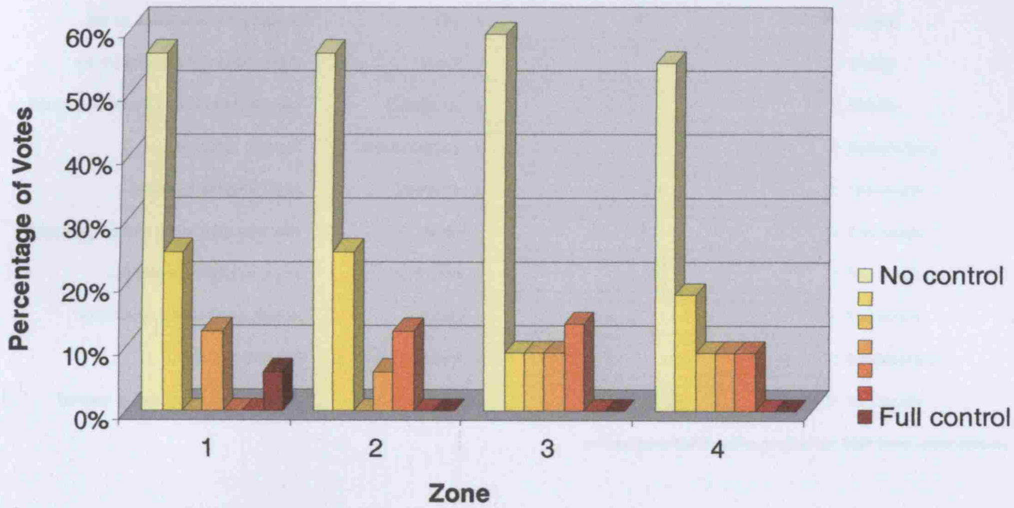


Figure (5.22):
Votes for perceived control over lighting in each of the 4 monitored zones


Temperature in winter: overall
Uncomfortable: 1
7: Comfortable
Temperature in winter: hot/cold
Too hot: 1
7: Too cold
Temperature in winter: stable/varies
Stable: 1
7: Varies during the day
Temperature in summer: overall
Uncomfortable: 1
7: Comfortable
Temperature in summer: hot/cold
Too hot: 1
7: Too cold
Temperature in summer: stable/ varies
Stable: 1
7: Varies during the day
Air in winter overall
Unsatisfactory: 1
7: Satisfactory
Air in winter: still/draughty
Still: 1
7: Draughty
Air in winter overall
Unsatisfactory: 1
7: Satisfactory
Air in winter: dry/humid
Dry: 1
7: Humid
Air in winter: fresh/stuffy
Fresh: 1
7: Stuffy
Air in winter: odourless/smelly
Odourless: 1
7: Smelly
Air in summer: overall
Unsatisfactory: 1
7: Satisfactory
Air in summer: still/draughty
Still: 1
7: Draughty
Air in summer: overall
Unsatisfactory: 1
7: Satisfactory
Air in summer: dry/humid
Dry: 1
7: Humid
Air in summer: fresh/stuffy
Fresh: 1
7: Stuffy
Air in summer: odourless/smelly
Odourless: 1
7: Smelly
Lighting: overall
Unsatisfactory: 1
7: Satisfactory
Lighting: natural light
Too little: 1
7: Too much
Lighting: glare from sun and sky
None: 1
7: Too much
Lighting: artificial light
Too little: 1
7: Too much
Lighting: glare from lights
None: 1
7: Too much
Noise: overall
Unsatisfactory: 1
7: Satisfactory
Noise: noise from colleagues
Too little: 1
7: Too much

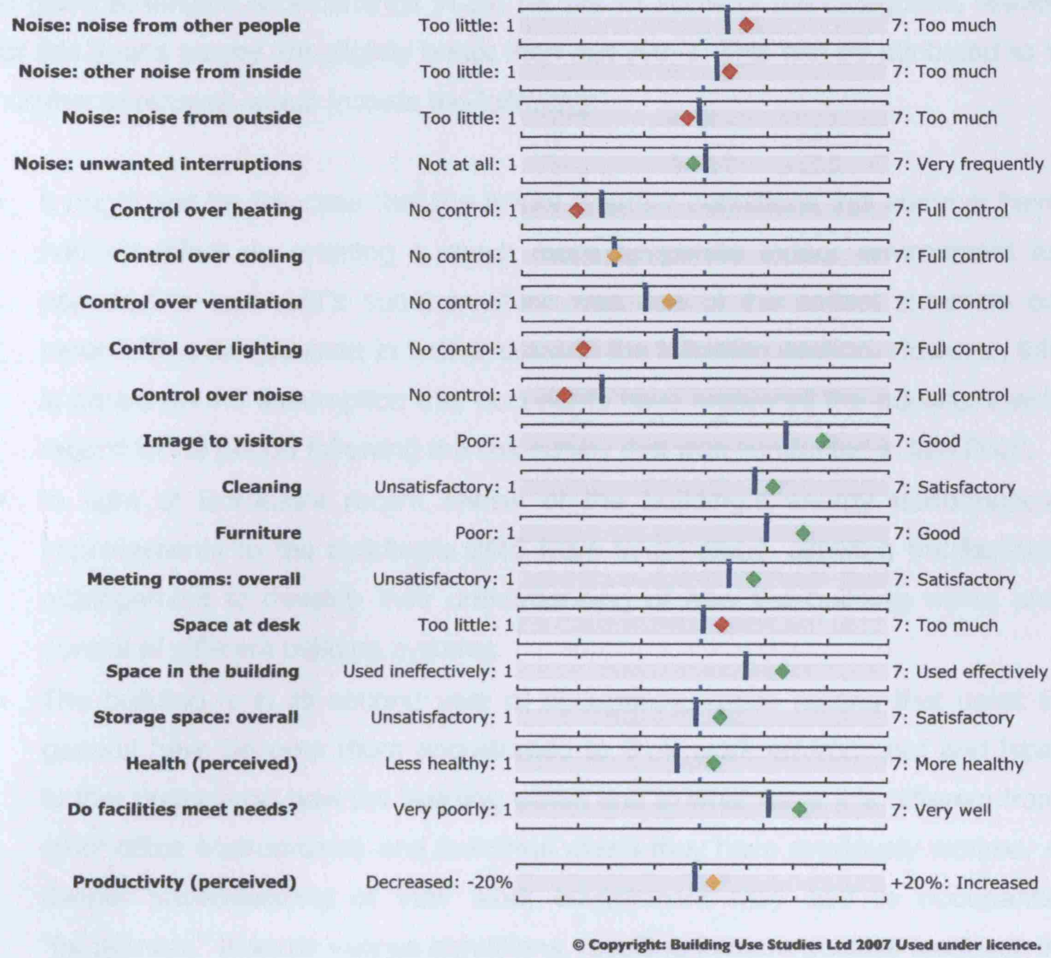


Figure (5.23):
Summary chart of the results of the main categories in the occupant survey conducted this year. The BUS benchmark values referred to, indicated by the blue lines through each scale, including UK buildings for the current study and an international database for the previous one. The green diamonds represent mean values significantly better or higher than both the benchmark and scale midpoint. Amber diamonds are mean values no different from benchmark. Red diamonds are mean values worse or lower than benchmark and scale midpoint.

In general, despite shortcomings in the results for some of the categories, results for this year's survey are slightly better than last year's. This can be attributed to a number of reasons which include the following:

- It might just be the case that the milder weather conditions this summer have had an effect on creating a much more temperate indoor environment as opposed to last year's summer which was one of the hottest summers on record. This can be seen in further detail in the following section. However, this is based on the assumption that occupants have answered the questions with regard to the period following the last survey that was conducted in late 2006.
- In light of Bordass's recent review of the building's energy performance, improvements to the building's BMS have taken place, allowing the facilities management to develop their understanding of how the building works and control of different building systems.
- The building is in its second year of occupancy, which means that users in general have become more accustomed to their work environment and have further understood how the building works and in what ways it is different from other office environments and buildings where they have previously worked. A deeper understanding of their work environment may add to occupants' "forgiveness" towards various conditions, resulting in more positive feedback in some cases.

5.3 Environmental conditions analysis

5.3.1 Thermal conditions analysis

Initially, the research set out to monitor overheating in the building over the summer and how that would affect perceived comfort conditions. However, due to temperatures being much lower than anticipated for July and August, particularly taking into account last year's record breaking heat [29], the data obtained from the monitoring is used to extrapolate results from last year's data, working backwards to calculate the dry resultant temperature (DRT), which is a more precise indicator for thermal comfort. Table (5.3) shows a summary of the results for the monitored variables in the 4 zones as well as outdoor conditions:

	Zone 1	Zone 2	Zone 3	Zone 4	Outdoor*
Air Temperature (˚C)					
MAX	24.4	23.9	23.2	23.7	24.3
MIN	18.6	19.2	18.7	19	12.7
MEAN	22.8	22.7	22	22.4	18.9
Radiant Temperature (˚C)					
MAX	24.4	23.63	23.24	24.01	-
MIN	18.28	18.28	18.66	19.04	-
MEAN	22.75	22.70	21.87	22.72	-
Relative Humidity (%)					
MAX	77.2	81.2	70.4	72.5	102.3
MIN	33.8	29.3	37	35.1	20.7
MEAN	55.3	53.8	54.9	54.7	70.7
Air Velocity (m/s)					
MEAN	0.06	0.05	0.05	0.07	-
Daylight Factors (%)					
MEAN	3.3	2.9	1.2	2.1	-

* The outdoor results were obtained from the BMS data for this summer.

Table (5.3):
Summary of the results for the variables that were monitored from 17/7 – 21/8/2007

In general, both radiant and air temperatures are within comfort boundaries for all of the zones. Figures (5.24) and (5.25) show time series graphs for air and radiant temperatures respectively, plotted alongside outdoor air temperature. According to the graphs, temperatures on both floors have remained within the boundaries of 20-23˚C despite fluctuations in outdoor temperatures reaching a low of 12.7˚C and a maximum of 24.3˚C. Figure (5.26) shows indoor and outdoor temperatures for zones 2 and 4 over the peak period on August 10th in further detail. According to the figure, there is a time lag of 2.5 hours, pushing indoor peak temperatures towards the evening on both floors. This indicates that the thermal mass used in the building's structure is absorbing the heat until it is saturated and effectively decreasing temperatures by around 1˚C for the first floor and 1.5 - 2˚C for the ground floor, which is heavier in its construction. Moreover, it is expected that in addition to thermal mass, shading and ventilation controls are contributing positively towards lowering peak temperatures in general with differences occurring between zones depending on their location within the building.

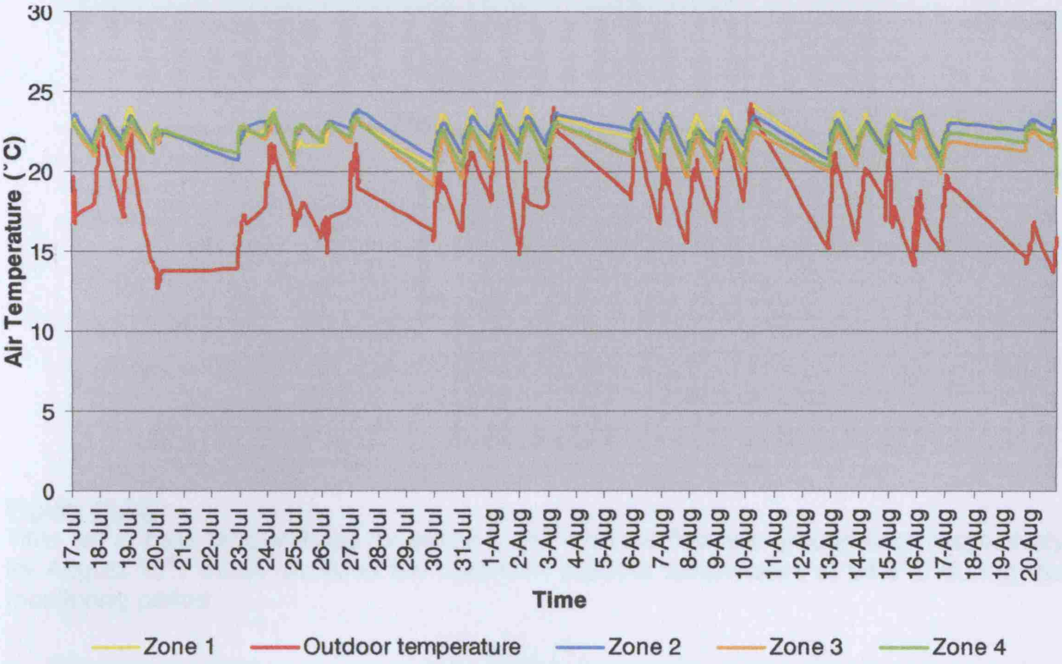


Figure (5.24):
Time series graph for indoor air temperature and outdoor temperature over entire monitoring period

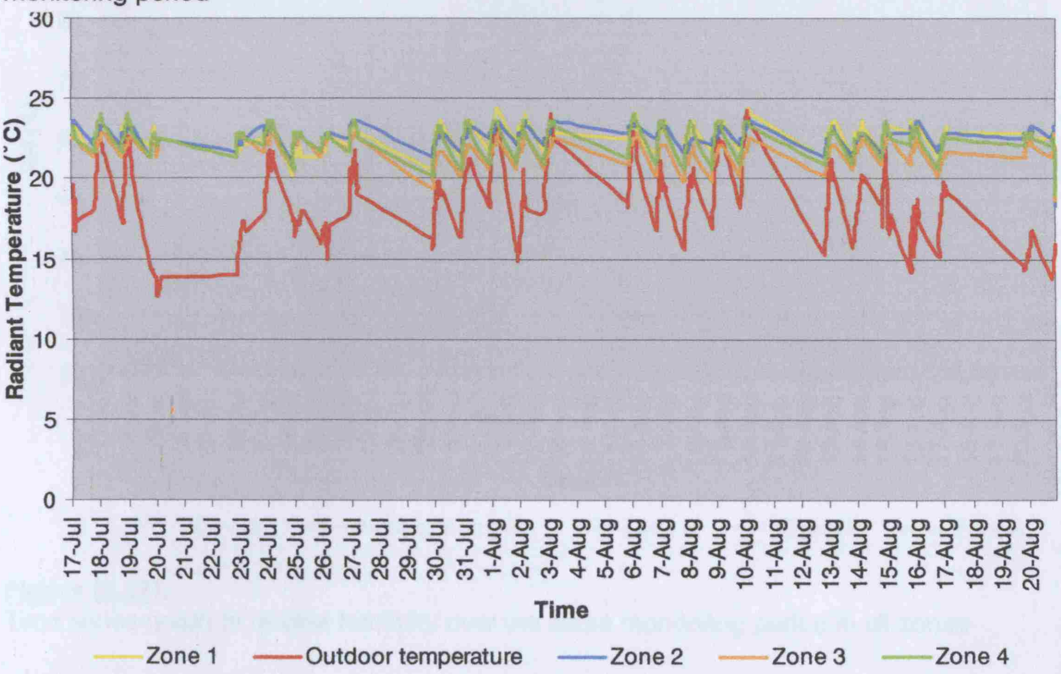


Figure (5.25):
Time series graph for radiant temperature and outdoor temperature

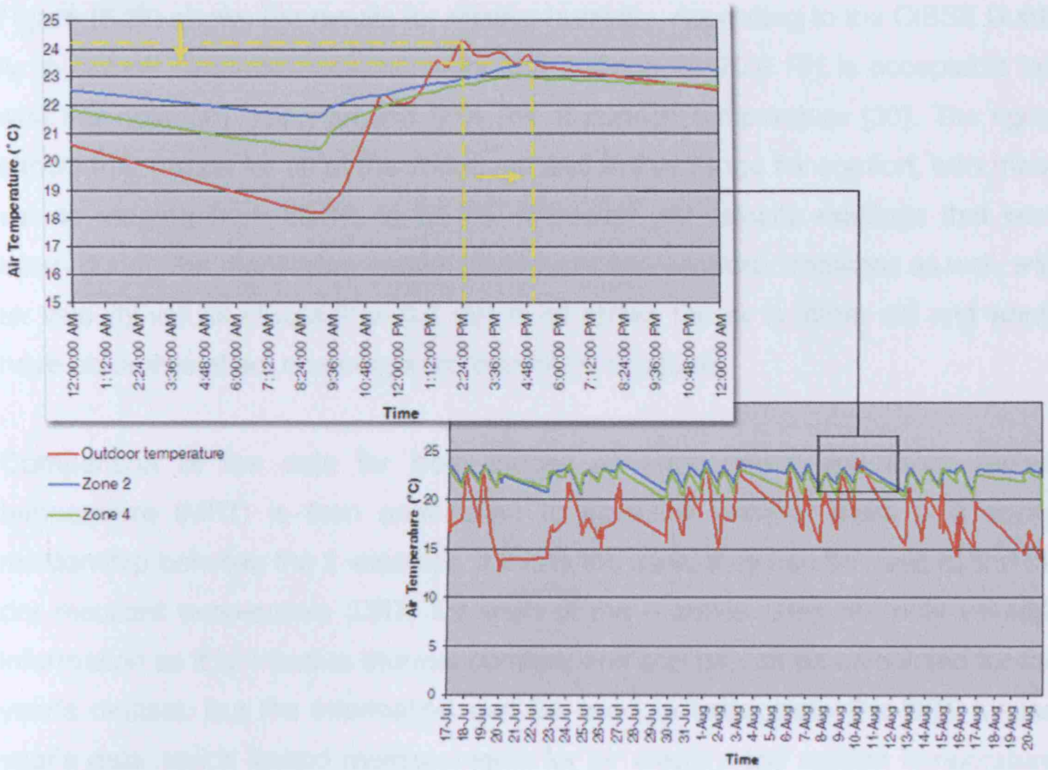


Figure (5.26):
Time lag in peak temperatures for zones 2 and 4 on the first and ground floor respectively for August 10th, which recorded the maximum outdoor temperature of 24.3°C during the monitoring period

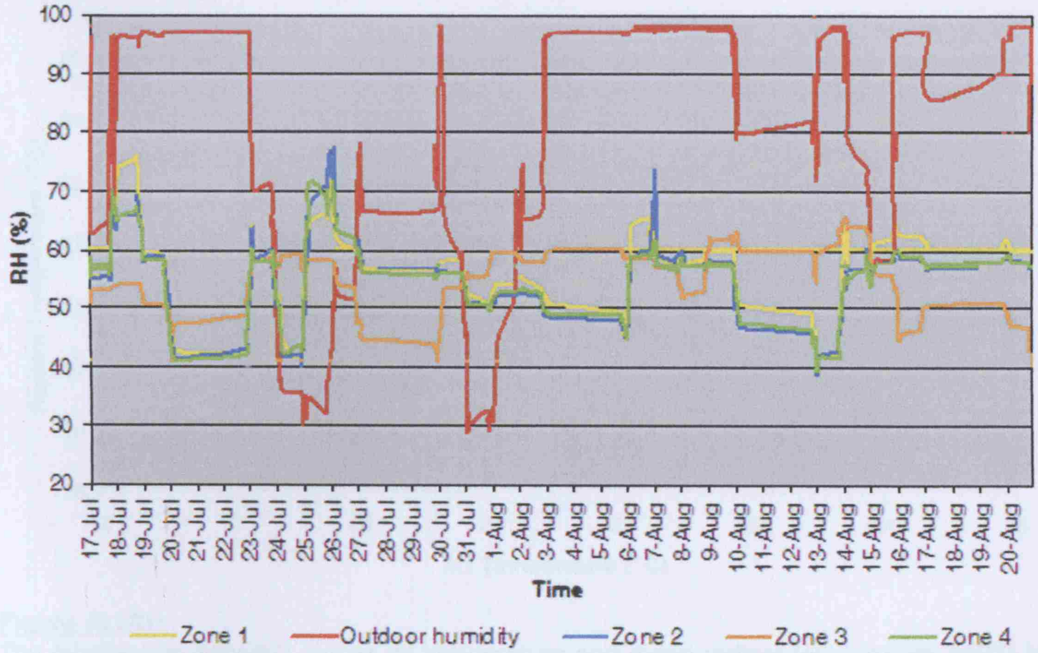


Figure (5.27):
Time series graph of relative humidity over the entire monitoring period in all zones

Figure (5.27) shows the results for relative humidity. According to the CIBSE Guide A, in normal circumstances, humidity in the range 40–70% RH is acceptable but with the optimum being around 65% RH at comfort temperature [30]. The figure shows that results for all of the zones are well in that range for comfort, with mean values ranging from 53.8% to 55.3%. Moreover, air velocity readings that were taken during the monitoring period place them into comfort conditions as well, with air velocity values of less than 0.1 m/s in all zones, the air is rather still and would have no or little effect on occupants' comfort in this case.

Comparison of the data for both indoor air temperature and mean radiant temperature (MRT) is then undertaken to establish whether there is a strong relationship between the 2 variables. If this is the case, they can be used to find the dry resultant temperature (DRT) for each of the 4 zones. This not only valuable information as it is linked to thermal comfort, and can be can be calculated for this year's dataset, but the information can be used to extrapolate the DRT for last year's data, which lacked measurements for air velocity and radiant temperature. So, in order to test the relationship between indoor air temperature and MRT, their values were regressed against each other for each zone and yielded the results shown in figures (5.28) to (5.31) below.

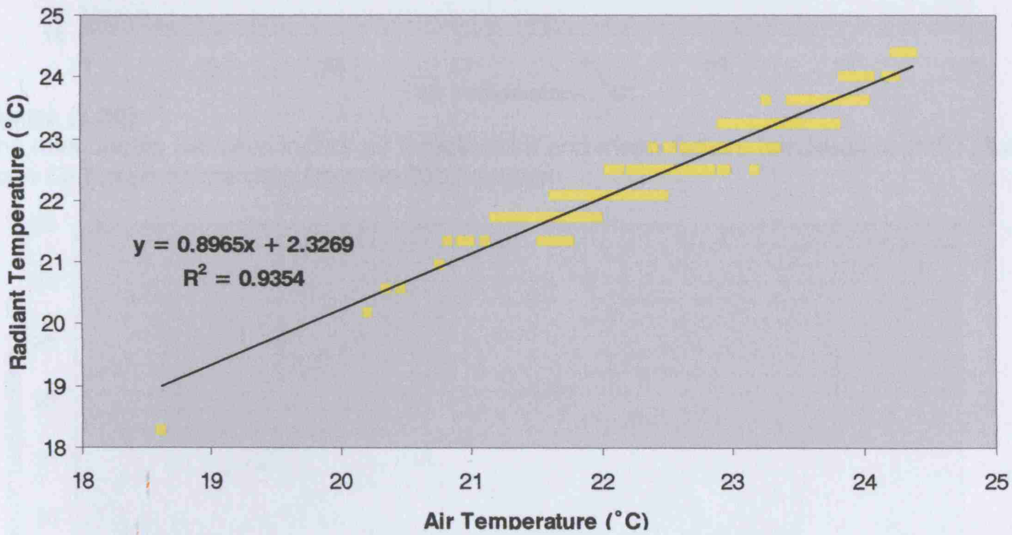


Figure (5.28):
The relationship between indoor air temperature and mean radiant temperature (MRT) for zone (1) based on the data from the 2007 dataset

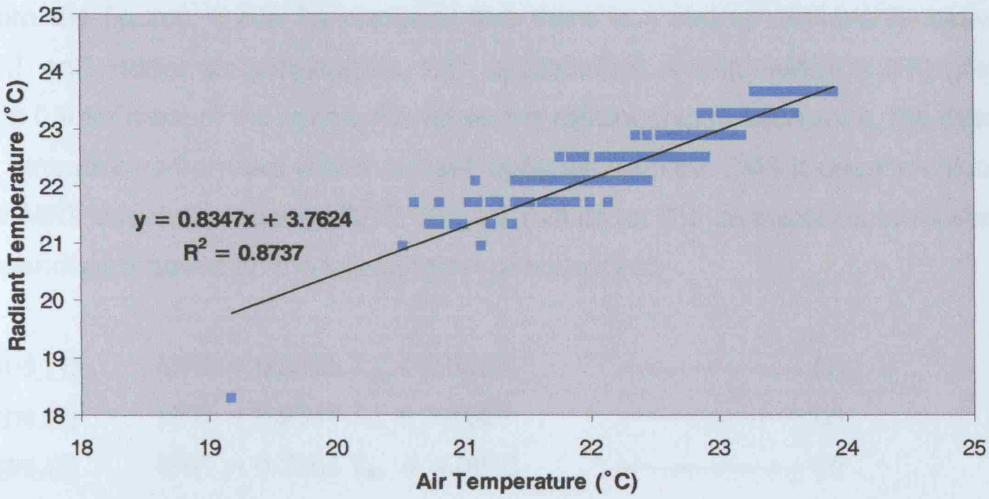


Figure (5.29):
The relationship between indoor air temperature and mean radiant temperature (MRT) for zone (2) based on the data from the 2007 dataset

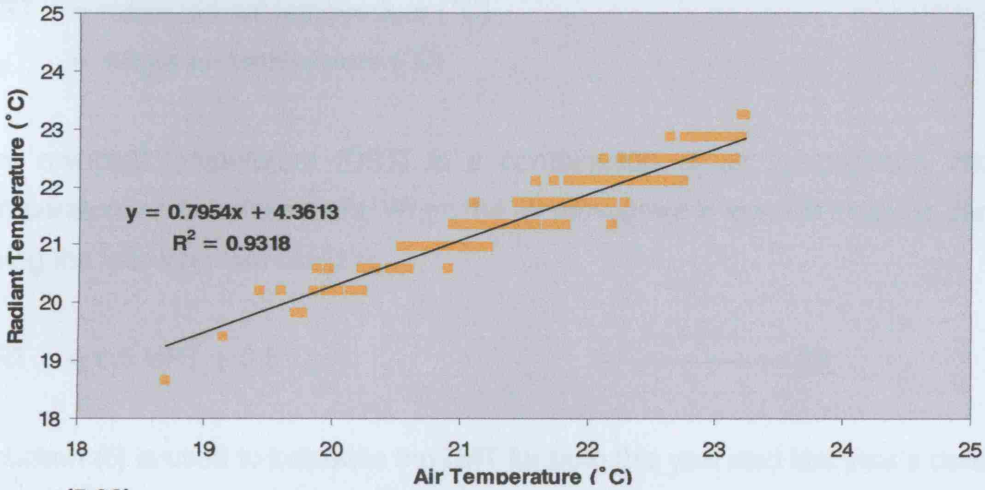


Figure (5.30):
The relationship between indoor air temperature and mean radiant temperature (MRT) for zone (3) based on the data from the 2007 dataset

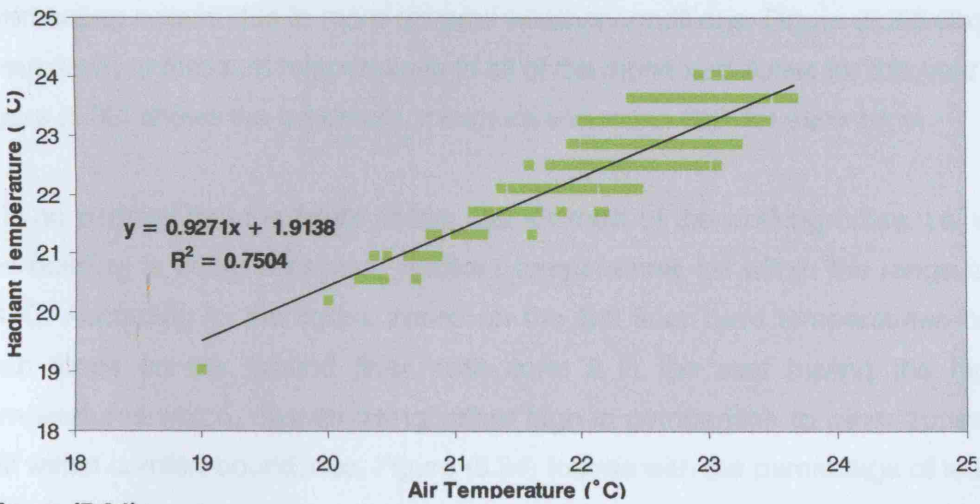


Figure (5.31):
The relationship between indoor air temperature and mean radiant temperature (MRT) for zone (4) based on the data from the 2007 dataset

From the figures, it can be deduced that there is a strong relationship between MRT and indoor air temperature, with a coefficient of determination (R^2) greater than 0.9 for most of the zones. Based on the relationship in each zone, the data for air temperature from last year's dataset, obtained from the BMS is used to calculate the MRT and subsequently DRT. The full results for the calculations are found in appendix 8.5 based on the following set of equations:

Zone (1) $MRT = 0.8965\, T_{air} + 2.3269$ ——— (1)

Zone (2) $MRT = 0.9347\, T_{air} + 3.7624$ ——— (2)

Zone (3) $MRT = 0.7954\, T_{air} + 4.3613$ ——— (3)

Zone (4) $MRT = 0.9271\, T_{air} + 1.9139$ ——— (4)

where:

MRT = mean radiant temperature (°C)

T_{air} = indoor air temperature (°C)

Dry resultant temperature (DRT) is a combination of air temperature, radiant temperature and air movement. When the air movement is low, DRT can be derived using the following formula [31]:

$DRT = 0.5\, MRT + 0.5\, T_{air}$ ——— (5)

Equation (5) is used to calculate the DRT for both this year and last year's datasets in order to compare conditions in the building for 2 scenarios: one where conditions are close to optimum values for comfort and the second when slight overheating occurs due to more extreme weather conditions. Figure (5.32) shows a breakdown of resultant temperatures in all of the monitored zones for this year, and figure (5.33) shows the maximum, minimum and mean DRT for each zone.

It is no surprise that the figure shows that for most of the working hours, i.e. when the building is being occupied, resultant temperatures fall within the range of 20-24°C. According to the figure, zones on the first floor have temperatures higher than those on the ground floor, with zone 2 in the east having the highest temperatures which, despite being rather high in comparison to other zones, are still within comfort boundaries. Figure (5.34) follows with the percentage of working hours where resultant temperatures exceed each value in each zone.

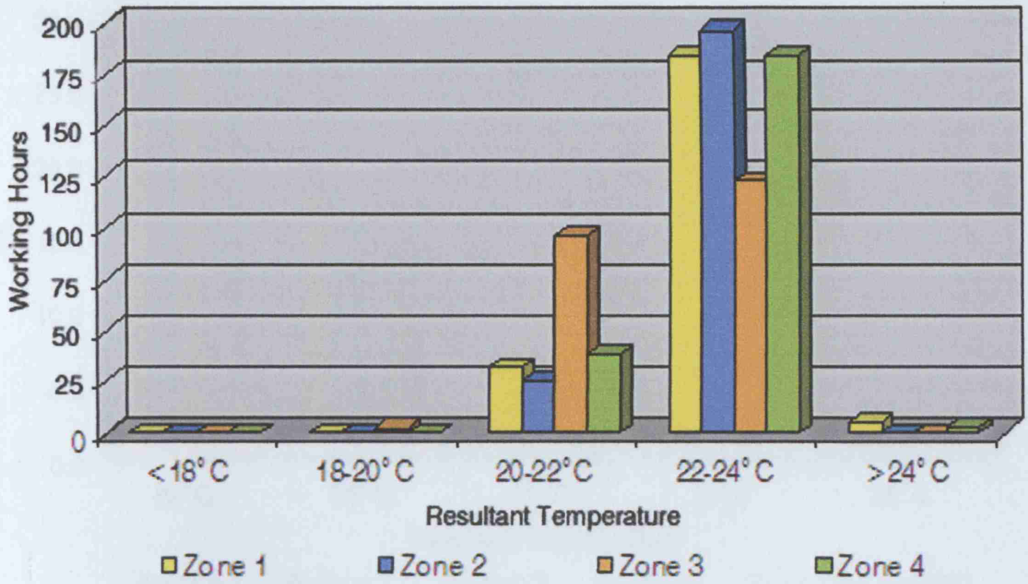


Figure (5.32):
Breakdown of resultant temperatures in all monitored zones for the 2007 dataset

Figure (5.33):
Breakdown of maximum, minimum and mean resultant temperatures in all monitored zones for the 2007 dataset

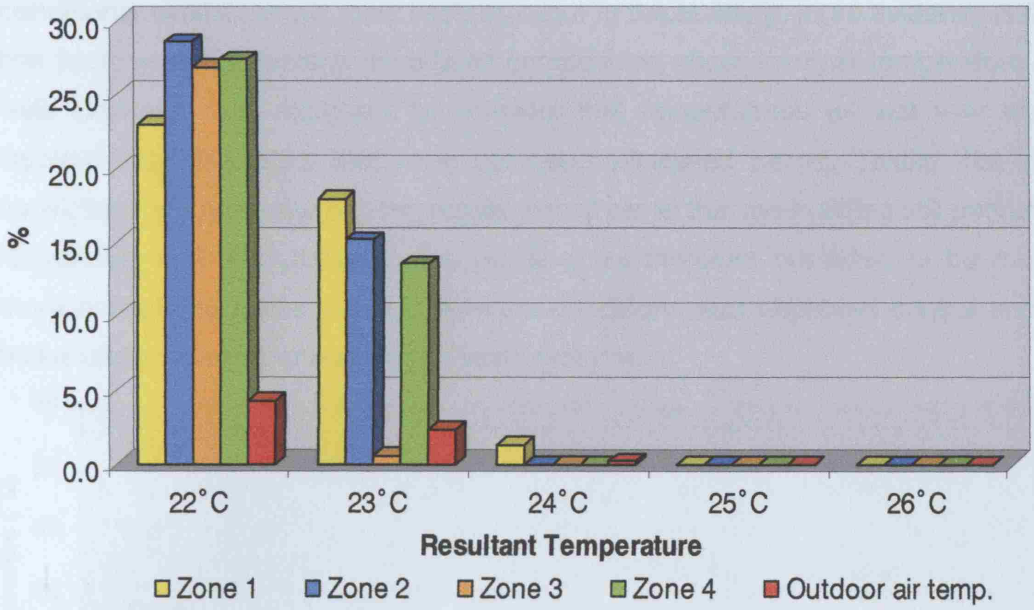


Figure (5.34):
Percentage of working hours exceeding each resultant temperature in each of the monitored zones for the 2007 dataset

The relationship between MRT and air temperature is used to find the DRT for two zones from last year's dataset, one on each floor. Last year's data from the BMS is used to find the indoor air temperature for the zones on both floors, TG04 on the ground floor and TG04 on the first, in addition to outdoor temperature. Both zones are located in the northern part of the building, adjacent to the north courtyard. First, the results for both air temperature and DRT are plotted against outdoor air temperature for the month of July 2006 in figure (5.35).

According to the figure, there is a higher fluctuation in temperatures as opposed to this year's conditions which are more stable. However, with the exception of peak temperatures on the first floor, the DRT falls between 20-28°C over a period when the peak outdoor temperature reaches a maximum of around 35°C, as can be seen in figure (5.36). The mean DRT reaches 23.9°C and 24.7°C for the ground and first floors respectively, both of which fall within comfort targets set out during the design of the building.

Moreover, according to figure (5.37), the percentage of working hours where the DRT exceeds 25°C is 6.5% for the ground floor and 5.1%for the first floor. Similarly, the percentage of working hours where DRT exceeds 28°C is 0.9% and 3.4% for the ground and first floors respectively. This shows that under hot summer conditions, overheating is most likely to occur in the building, more evidently in the first floor, where occupants have been complaining about summer temperature as well. However, it is important to consider that temperatures for last year were atypical, reaching highs that have not been witnessed before. Taking that into consideration and examining the results would prove that the building still performs reasonably well. Conditions in the building are therefore predicted to be much more acceptable under average summer conditions with improved control and a better understanding of building services systems.

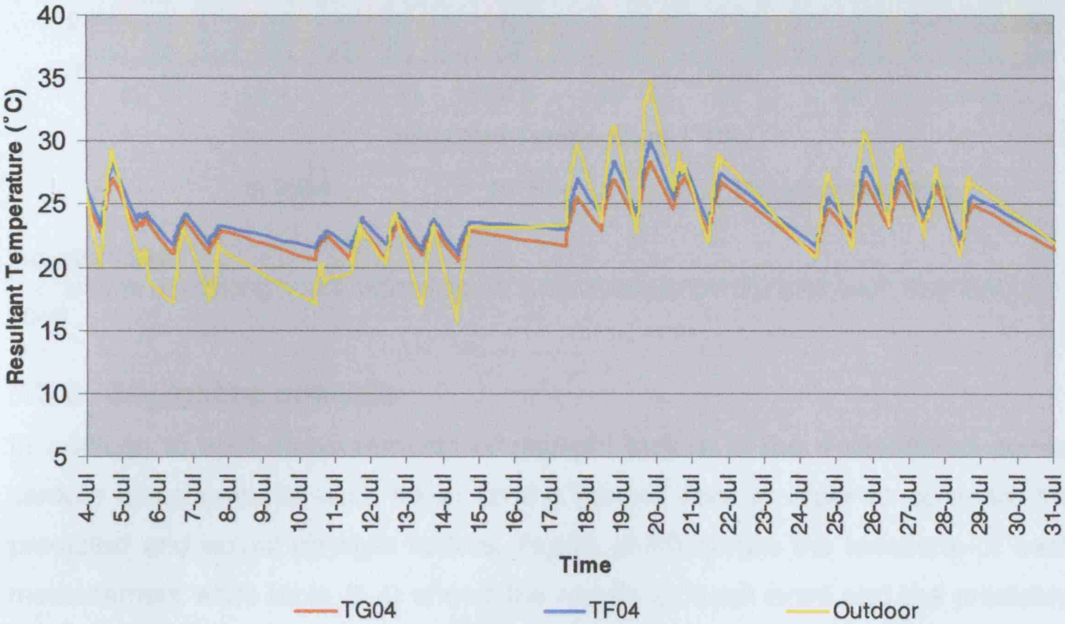


Figure (5.35):
Time series graph for DRT temperature and outdoor temperature over the month of July 2006

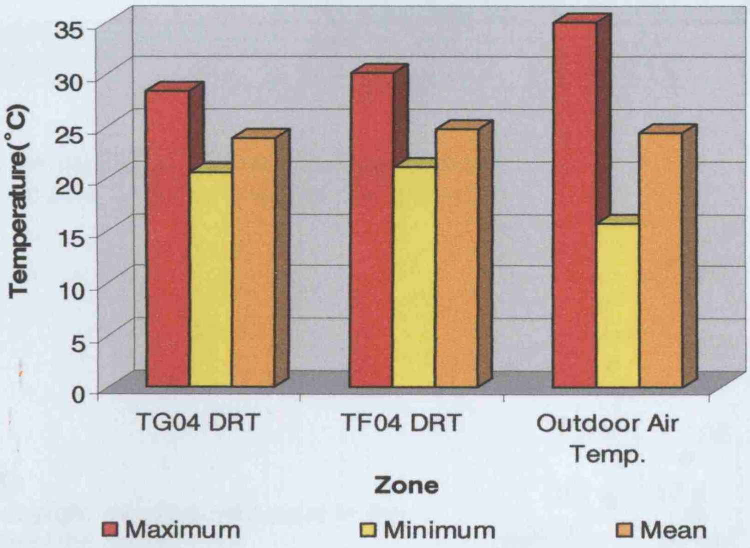


Figure (5.36):
Breakdown of maximum, minimum and mean calculated resultant temperature on both floors for 2006

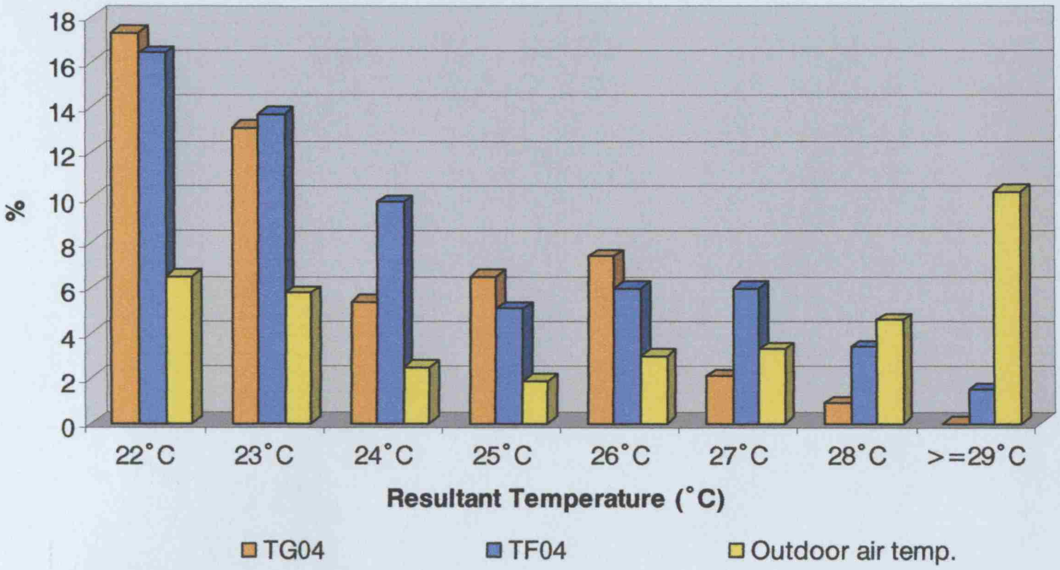


Figure (5.37):
Percentage of working hours exceeding each resultant temperature for each floor for July 2006

5.3.2 Daylighting analysis

In addition to spot measurements of daylight factors in the 4 monitored zones, sample measurements were taken on the ground floor in order to compare the predicted and actual daylight factors. Figure (5.38) shows the locations of each measurement while table (5.4) shows the results for each point and the predicted DF for the same point from the lighting simulation during the design stage.

	P1	P2	P3	P4	P5	P6
Predicted DF (%)	13.6	5.4	6.2	2.0	1.9	2.1
Measured DF (%)	8.8	3.4	8.9	2.1%	0.5	0.3

Table (5.4):
Summary of the results for predicted and measured daylight factors over 2 sample areas on the ground floor.

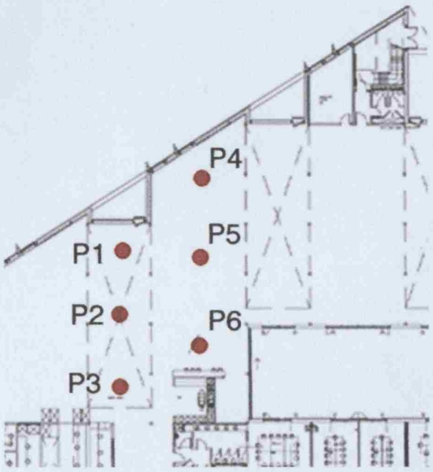
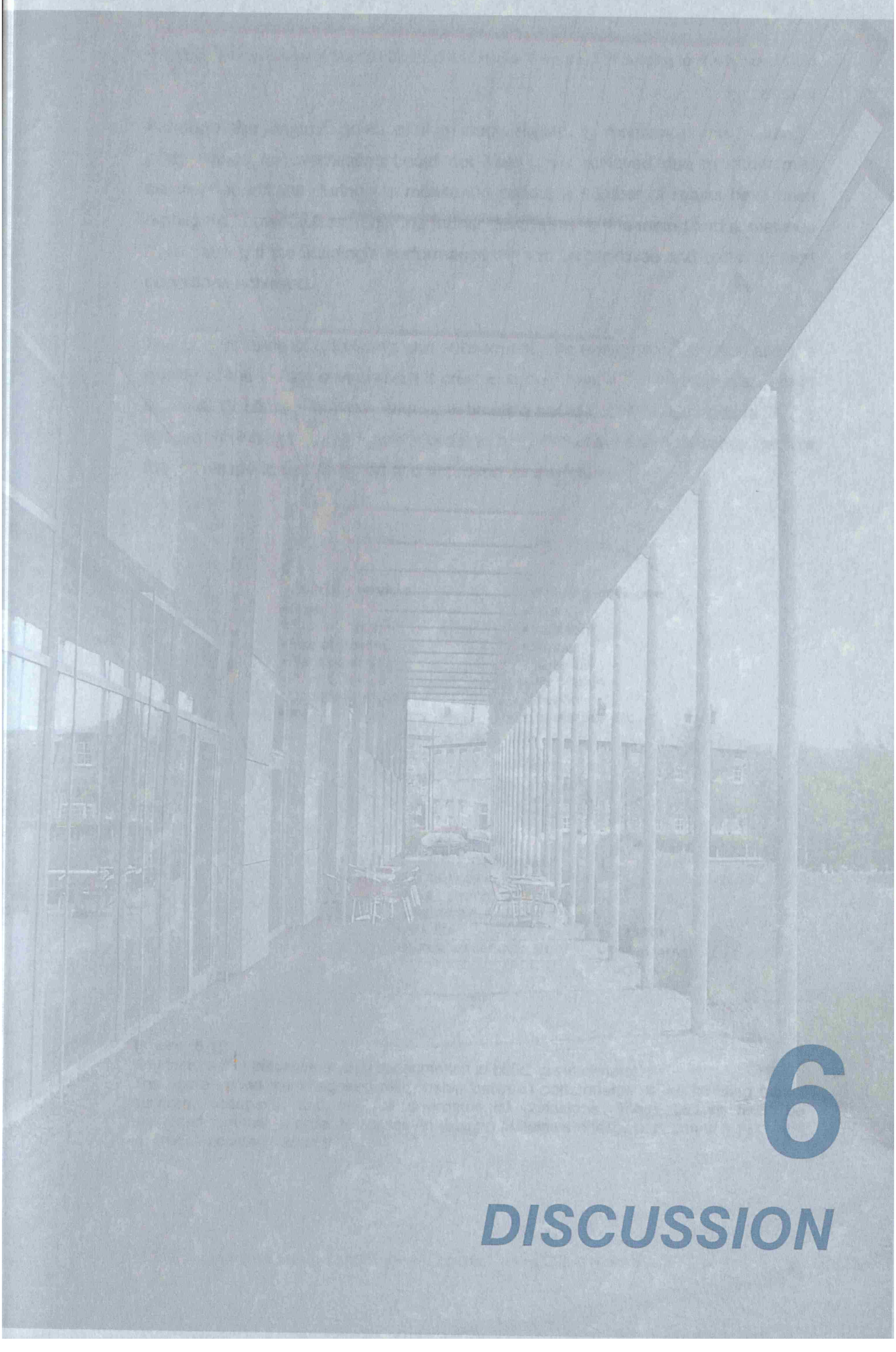


Figure (5.38):
Location of daylight measurement point in the northern zone of the ground floor



6

DISCUSSION

Although the original goals of this study regarding monitoring the building's performance for overheating could not have been achieved due to rather mild summer conditions during the monitoring period, a number of issues have been highlighted nevertheless, requiring further development, fine tuning and sometimes even solving if the building's performance were to be improved and better comfort conditions achieved.

The performance of a building and subsequently its energy consumption and the quality of the indoor environment it creates is determined by the factors shown in figure (6.1): climate, building envelope, building services and human factors [32]. It is worth revisiting this key figure in order to highlight where and how some areas of the Heelis are to be fine tuned and improved for the future.

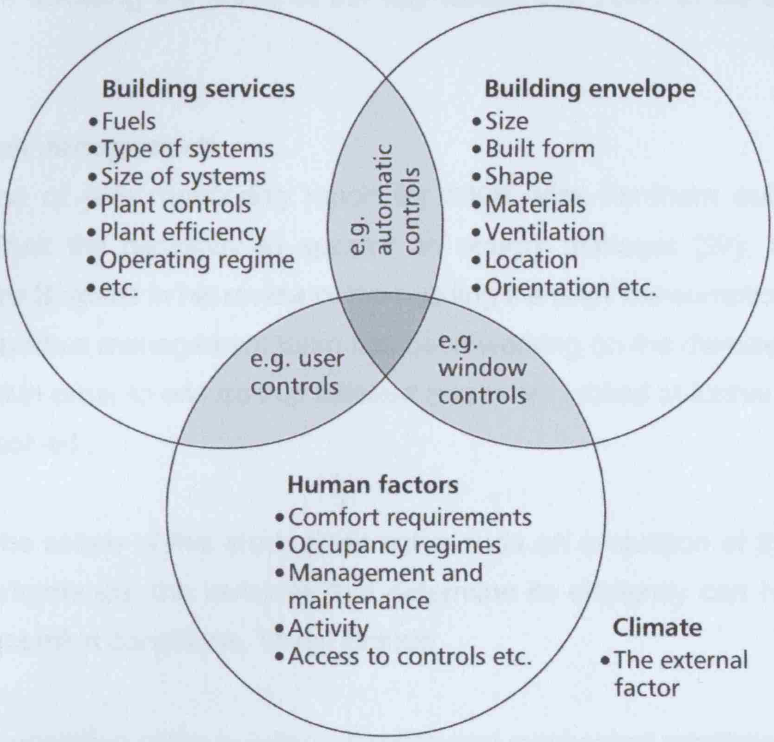


Figure (6.1):
Key factors that influence energy consumption in buildings in general.
The figure shows the integrated relationship between components of the building fabric, services, occupants and external environmental conditions. These factors must be examined together in order to assess an existing building's energy consumption to a high degree of accuracy, *source [32]*

Because predicting external conditions is virtually impossible, proven to a large extent by summer temperatures for this year as opposed to last year's recorded breaking heat, focus should be drawn towards the integrated relationship between the factors that influence a building's performance, i.e. the shaded areas in figure (6.1). In general, post occupancy evaluation is an interdisciplinary field that combines variables from different areas related to human activity and the natural and built environments.

Improvements to one or more variables will have an effect on many other factors, which makes change in this area both easy and difficult at the same time: easy because of multiple benefits that can be achieved and difficult for the unpredictability of results of different corrective measures that can be taken. Based on the figure, the analysis of environmental conditions and results of the occupant survey, the following are some of the key issues that need to be addressed at Heelis:

- **Building management:**

In their end of year monitoring report for 2006, Max Fordham outlined to the National Trust the necessity to appoint an energy manager [27], a point also reiterated by Bordass in his review of the building's energy consumption. Since last year, the facilities management team has been working on the development of the department in order to ensure that different issues are looked at further and various problems solved.

Although the scope of this study does not include an evaluation of the building's energy performance, the variables that determine its efficiency can have a direct impact on comfort conditions. These include:

- Proper operation of the building's heating and mechanical ventilation systems
- Proper maintenance of plant controls
- Ventilation controls for the snouts, perimeter windows and courtyard windows
- Lighting controls on both floors
- Recording any unusual behavior in different building systems that would cause conflicts in the building's operation, like the windows opening in winter when it

is too cold outside for example or lights left on even when there is ample daylighting available on sunnier days

- **Daylighting**:

Although the scope of the project and the time provided did not allow for a comprehensive daylighting study to be conducted, spot measurements that were taken in each of the monitored zones have shown a substantial difference between predicted values for daylight factors and measured values on both floors, with the latter being as low as half the predicted in some cases (see table 5.4)

It has been highlighted that uneven distribution of natural lighting across the floor plate might be a problem [23], which was proven to some extent through this study. One of the most important characteristics of this building in particular, is its pioneering use of daylighting in an office environment. In order for this to continue to be true, the issue of uneven distribution and low DF in some parts of the building on the ground floor must be addressed and improvements must be sought to achieve higher DF levels. Lighting controls are also important in order to guarantee proper use of artificial lighting at times when it is needed only.

- **Controls**:

Building controls form the link between the occupants, the building fabric and building services systems. Results from the occupant survey have shown that in general, occupants at Heelis feel they have no control over any of the main service systems, including ventilation and lighting. This would usually be fine, provided the BMS system is properly maintained and updated according to occupants' needs and internal conditions.

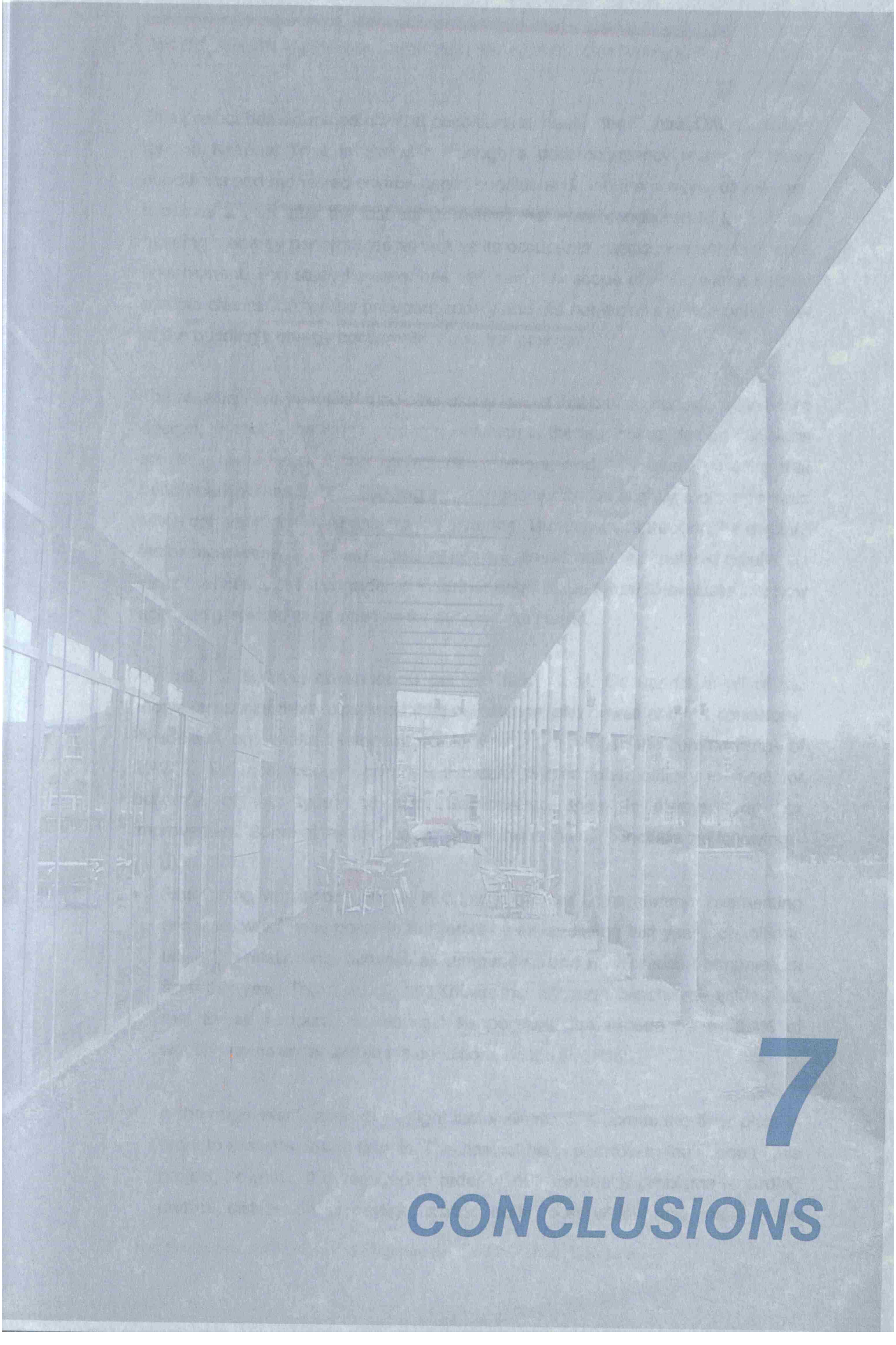
Furthermore, overrides should be used with caution, as "too much" control might have adverse effects on the indoor environment and increase energy consumption. A full review of the control systems is recommended in order to fine tune their performance, particularly windows and ventilation controls as well as lighting. Particular attention should be made to conflicting operations, where for example, the windows would open if the heating is on or the lights might be turned on if there is no need for them during sunny days.

- **Occupants' awareness and understanding of building environment:**

As soon as occupants and visitors enter Heelis, they realize that it is not the typical office environment that they might have been accustomed to. In an effort to raise occupants' awareness towards their work environment, an "occupant guide" was compiled to introduce users to the building's BMS and manual control mechanisms for windows, heating, lighting and office equipment. In addition, it includes simple "energy do's and don'ts" which highlight energy efficient practices that can be adopted by occupants themselves to save energy and maintain their working environment at optimum conditions.

Naturally ventilated buildings are far more unpredictable than other built environments. This is why an occupant guide is an important step towards creating a better understanding of the building's sensitivity towards any changes brought on by natural or man induced circumstances. It is recommended that the occupant is kept up to date with any changes in the building's systems and circulated regularly among staff.

In general, this study has highlighted how post occupancy review is an important tool to predict buildings' performance not only from current data but working with previous information to predict variables that were not measured at the time. A periodical and systematic approach is required to carry out different reviews of the same building through regular time intervals, where specific aspects of its performance can be examined each time as time and resources do not usually permit for full, comprehensive studies to be conducted each time.



7 CONCLUSIONS

This project has examined comfort conditions at Heelis, the Central Office Building for the National Trust in Swindon through a post occupancy review of these conditions and monitored environmental conditions during the summer of this year. It comes a year after the last set of reviews that were conducted to look at the building's energy performance as well as its occupants' satisfaction with their work environment. This study however has had a smaller scope of work, with a smaller sample distribution for the occupant survey and did not include a thorough review of the building's energy consumption over the past year.

The research has identified a number of key issues that can be considered in future designs. Perhaps the most important of which is the fact not all design decisions are fully considered during project development, and it is often the case that benchmark values for the building's performance can be slightly more optimistic when compared to actual data from monitoring. This is evident through the daylight factor measurements, where actual values are almost half the simulated results, an issue that needs to be considered in further detail in the future to evaluate just how accurate predicted values can be for building like Heelis.

Overall, the building continues to perform rather well. Occupants in all of the monitored zones have expressed their satisfaction with overall comfort conditions. In addition, dry resultant temperatures for this year fall within the comfort range of 20-24°C for most working hours, a standard that is rather difficult to meet for buildings of this type and size. Nevertheless, there is always room for improvement. Some of the main areas where this is the case include the following:

- Fine tuning ventilation controls in order to overcome the summer overheating scenario, which was possible to predict by extrapolating last year's conditions using the relationship between air temperature and mean radiant temperature from this year. The research has shown that although benchmark values are met for air temperature, resultant temperature can exceed up to 3.4% of working hours under last year's conditions on the first floor.

- A thorough examination of daylight factor distribution across the floor plate in order to evaluate design targets. This has not been possible in the scope of this project; however, it is required in order to overcome any problems regarding uneven distribution of daylight across both floors which may result in an increase in energy consumption from artificial lighting that is used to solve the problem, perhaps when there might not be a serious one to begin with.

- Improving BMS control mechanisms and manual overrides to ensure better winter and summer ventilation and indoor temperature. This is important in order to avoid contradicting mechanisms and occupant misuse of manual controls.

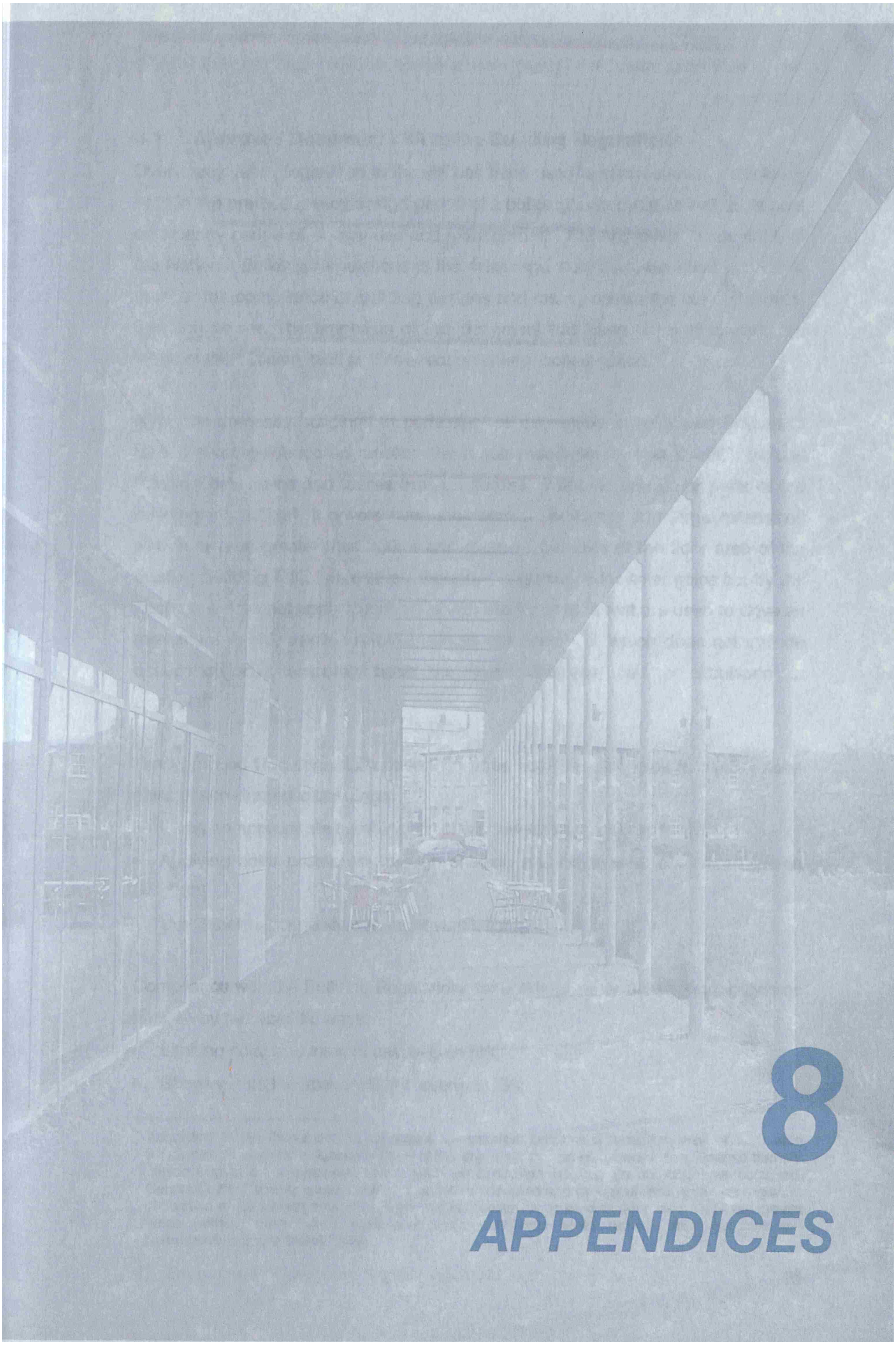
Although this year's research has not managed to provide some insight into the building's performance for overheating, it was possible to predict variables that were not measured last year and give further insight into its performance under last year's conditions. This in itself is perhaps the most valuable lesson to be learned from post occupancy evaluation as a post design tool. It is important to conduct it more periodically and systematically, examining different variables each time if designers were to evaluate buildings in further detail after their completion. Additional future work that could be beneficial as suggested by this study includes:

- Conducting a second, more thorough evaluation of the building's energy performance in order to assess to what extent have previous recommendations been taken into consideration and highlight any new issues that might arise.

- Conducting a detailed evaluation of lighting, both natural and artificial, in the building. This would enable both designers and building management to assess design targets and focus on areas of concern, whether to occupants' comfort or from an energy consumption perspective.

- Updating the user manual to include further information about the building and its performance. It would be useful for occupants themselves to know how well is their work environment performing and what they can do to maintain comfort conditions at satisfactory levels.

- Exploring comfort related factors (temperature, air quality and velocity, lighting, control and noise) in further detail how they might be linked to energy consumption and overall building performance.



8 APPENDICES

8.1 Approved Document L2A of the Building Regulations

Over many years, legislation in the UK has been used to enforce energy efficiency both in the pre-occupancy design period of a building's life cycle as well as its post occupancy period of energy use and management. The Approved Document L of the National Building Regulations is the main regulatory document that is used to monitor the compliance of building designs and mainly covers the conservation of fuel and power. The emphasis of this document has been directed towards the fabric of the building itself and its effect on energy consumption.

New non-domestic buildings in particular are addressed in Approved Document L2A. It gives guidance on meeting the requirements set by Part L which include "limiting heat gains and losses through thermal elements and other parts of the building fabric."[33]. It covers new non-domestic buildings and large extensions with floor area greater than 100m² and greater than 25% of the floor area of the existing building [33]. Interestingly though, the guidance for solar gains set by the document does not apply to buildings with stacks or atria that are used to drive air movement. It only applies if these spaces are occupied, which does not include occupancy on a temporary basis like spaces that are used for circulation for example[#].

The Approved Document L2A describes three possible strategies to control solar gains in non-domestic buildings:

- Using an appropriate combination of window size and orientation [33]
- Applying solar protection through shading and other solar control measures [33]
- Using thermal capacity with night ventilation [33]

Compliance with the Building Regulations for buildings other than school buildings is given by two specific ways:

- Limiting solar and internal casual gain [33]
- Showing that the space will not overheat [33]

[#] According to the Document, "If an atrium, for example contains a reception area or restaurant where people work for a substantial part of the day, then it is an occupied space. Spaces that are only occupied on a temporary basis, such as circulation spaces, do not count as occupied. Generally, the following areas would not count as occupied and no calculation would be required: circulation areas (unless they contain permanent workstations as described above), IT equipment areas (without desk based staff) and public circulation areas (unless staff members are permanently working there)." [33]

Compliance with the Building Regulations would require designers to show "that the combined solar and internal casual gains in a building on peak summer days (corrected for geographical location) does not exceed 35 W/m^2 of floor area in each occupied space" [33]. Furthermore, compliance can be proven by showing that the "operative temperature in a certain space does not exceed an agreed threshold for than a reasonable number of occupied hours per annum" [33], which in turn, depends on the activities within the space itself.

8.2 Building Performance Evaluation (BPE)

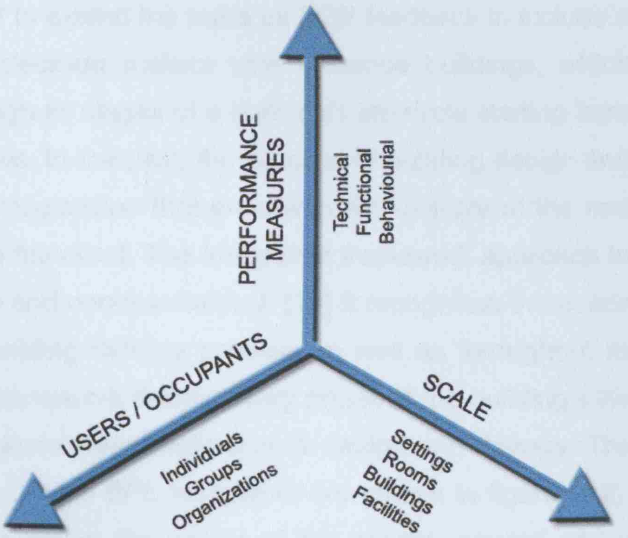
8.2.1 The evolution of BPE

Adapting its theoretical foundation from the field of cybernetics[§§], building performance evaluation (BPE) can be defined as "the process of systematically comparing the actual performance of buildings, places and systems to explicitly documented criteria for their expected performance". [19] It is based on the post occupancy evaluation (POE) model developed by Preiser, Rabinowitz and White in 1988. A "systems" approach is adopted for the field as it holistically links all the variables in the process of design that link the built environment and concept of space together with social and cultural aspects of design, inadvertently having an effect on BPE as a whole. Furthermore, the systems approach successfully represents the interactive nature of relationships between people and their surroundings, where humans, in general, adjust to a dynamic, constantly changing environment.

As a result of the interaction between individuals and the range of setting in the built environment, a number of human needs arise and are redefined in this context as "performance levels" [19]. They represent a hierarchy of users' needs, priorities and expectations[***] of the performance of their surrounding built environment. This hierarchal system relates directly to the intuitive nature of humans along with the building's elements and settings. The result is a realization that the physical environment is much more than just a building or shell due to the focus on spaces and settings that are used for particular activities by users. The variables of building performance can be seen in figure (8.1). The figure clearly demonstrates the interdependency between occupants and both the scale and performance measures of the physical environment. The latter has been broken down into these two divisions in order to demonstrate that in a sense, buildings are also dynamic and evolving to suit the needs of their occupants.

§§ Cybernetics is "the study of human control functions and of mechanical and electronic systems designed to replace them, involving the application of statistical mechanics to communication engineering" (Infoplease Dictionary, 2003) [19]

*** Grossly based on Maslow's human needs hierarchy (1948), the historic approach to setting priorities on building performance has been transformed into a system of users' needs and later synthesized into the "habitability framework" which includes 3 levels of priority: health, safety and security performance; functional, efficiency and work flow performance; and psychological, social, cultural and aesthetic performance. [19]



<u>Figure (8.1)</u>:
Building performance variables,
Source [19]

One of the goals of BPE is to improve the quality of decisions made at every phase of a building's life cycle, from strategic planning to programming, design and construction, all the way to facility management and adaptive reuse. POE is often viewed as sub-process of BPE, but a very important one nevertheless. It can be defined as "the act of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time". [19] So far, POE has focused primarily on users' experience of buildings' performance.

As essential this step has been in bridging the gap between a building's design and actual performance, the future of POE suggests a shift towards adopting a more holistic approach to evaluation that is more process oriented. This would enable one to consider a number of factors in addition to the facilities themselves, including organizational, political, economic and social forces that shape them. [19] Despite being a subset of the larger, more intricate process of BPE, POE is perhaps one of the most important as it zeroes in onto that part of the building's life cycle where most shortcomings are likely to occur: occupancy and facilities management. It is during this phase that design targets and decisions are truly put to the test, often undergoing forces that were either underestimated during the design or sometimes never anticipated in the first place, including the most unpredictable factor off all: the occupants.

8.2.2 BPE: A conceptual framework

A framework for BPE was developed to extend the basis for POE feedback to include a broad range of stakeholders and decision makers who influence buildings, which enable POE's to be applicable through all stages of a building's life cycle starting from the early stages of the design process. In the past, the process of building design and delivery was perceived as a linear progression that ends with the delivery of the end product, in this case the building, to the client. The integrative framework approach to BPE in contrast is dynamic, evolving and non-mechanical. [19] It recognizes the needs of performance evaluation in the building delivery process as well as throughout its entire life cycle. Moreover, the BPE framework defines every phase in the building's life cycle from the point of view of all stakeholders involved in its design and delivery. The different phases and feedback loops of the BPE framework are shown in figure (8.2), where building performance criteria are at the center of the model, around which revolves the framework during every phase in a cyclical manner.

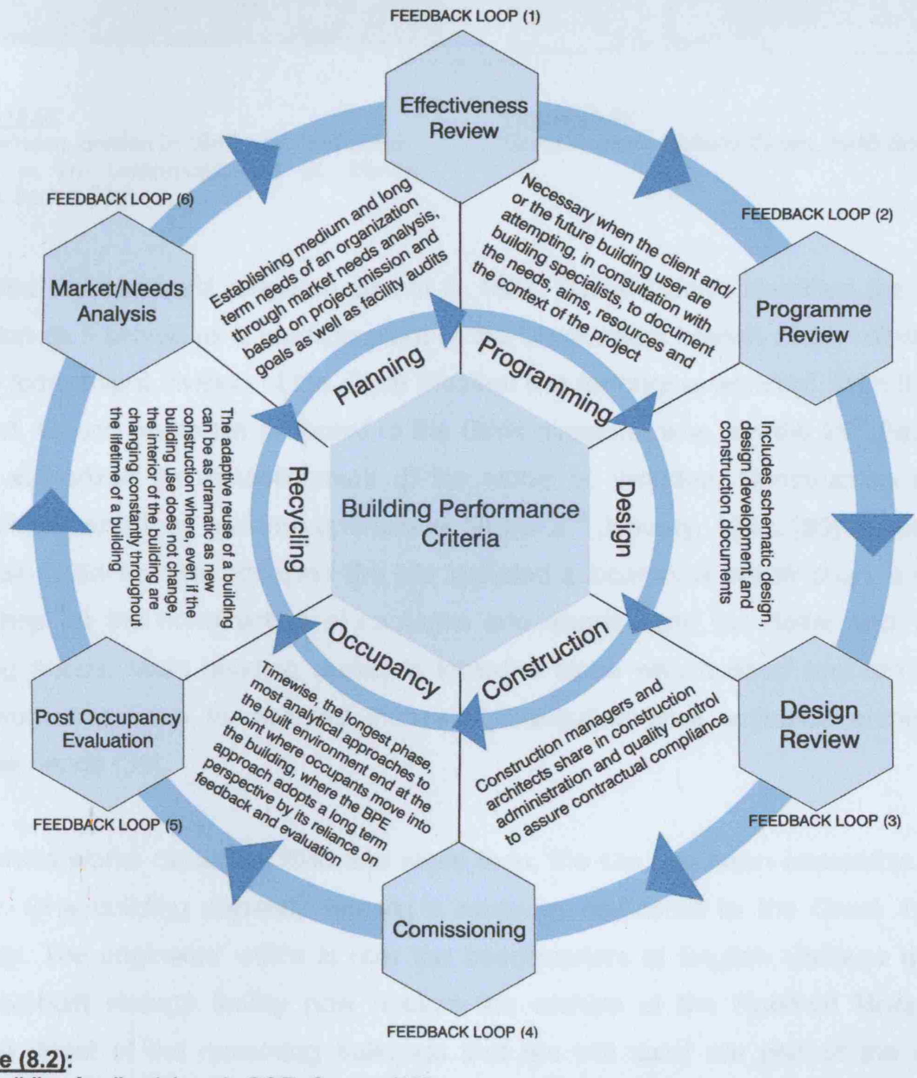


Figure (8.2):
The building feedback loop in POE, *Source [19]*

8.3 Site context and the sustainable policy of the National Trust

Located on the site of the Great Western Railway (GWR) works in Swindon, Wiltshire, one of the key architectural challenges of the Heelis building was identified from the early stages of the design that it should be an "appropriate 21st century response to a highly significant historic site" [23]. Gaining its significance in 1840, with the extension of the Great Western Railway through the town of Swindon and serving as a branching point to Cheltenham and Gloucester, the site plays an important role in the Railway Heritage of the area as a whole.

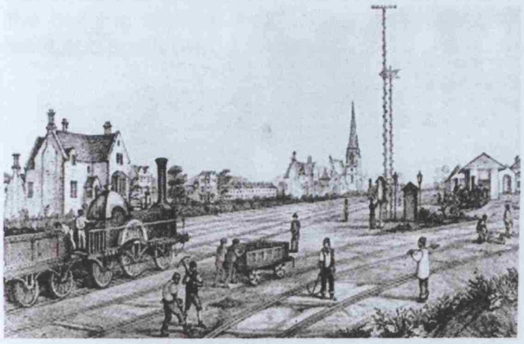


Figure (8.3):
The Swindon junction in 1847 with the Railway Village in the background and St. Mark's church. *Source [34]*

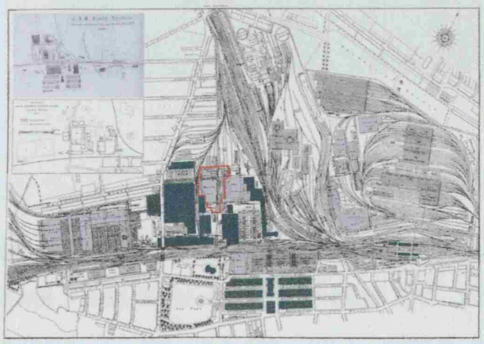


Figure (8.4):
Great Western Railway Works, 1946 *Source [23]*

Recruited by Isambard Kingdom Brunel in 1837, Daniel Gooch identified the site at Swindon as it served as a junction point of the Cheltenham branch of the railway and also a "convenient division of the Great Western line for engine working". With Brunel's support, Gooch made his proposal to the GWR directors, who, on the 25th February, 1841, authorized the establishment of the works at Swindon. Construction started immediately and they became operational on the 2nd January, 1843. [35] At the time, the main buildings that occupied the site included a locomotive repair shed, a central workshop for the construction of carriages and wagons and the Boiler and Tender making shops. Main building materials included stone with trussed roof structures. Brickwork was used for inverted arches at foundation level, entrance arches and window heads [34].

The whole works closed in 1986 and since then, the site has been accessible to the public. One building currently houses a museum dedicated to the Great Western Railway. The engineers' office is now the headquarters of English Heritage and the purpose-built storage facility now houses the archive of the National Monuments Record. Most of the remaining buildings that are still used are part of the current

Designer Outlet Village. It is in fact because of the latter, a main shopping facility in the area, that the site witnesses an increase in visits by the public.

Figure (8.5):
Aerial view of the site at present with the orientation of the building and the main approaches from the north-west and south east, *Source [23]*

Founded in 1895 to guard the process of acquisition and protection of threatened coastline, countryside and buildings, the National Trust now cares for over 248,000 hectares (612,000 acres) of countryside in England, Wales and Northern Ireland, in addition to more than 700 miles of coastline and more than 200 buildings and gardens of interest and importance. As a charity organization, the Trust recognizes the need and urgency for shared efforts to mitigate the causes and adapt to the impacts of climate change as a global phenomenon [36]. Its stewardship of various natural and historic built environments has led the National Trust to adopt an environmental strategy that would promote crucial issues like sustainability and the minimization of environmental footprints of buildings and people who work for the organization. In their 2010 Strategy, the National Trust outlines a number of plans to promote their growing awareness to the environment, including:

- The reduction of the Trust's environmental footprint and sharing their successes and failures in the process of doing so
- The investment in energy efficiency and microgeneration to community-scale renewables and low carbon settlements
- Supporting the public in adopting a more "environmentally friendly" lifestyle
- The promotion of sustainable land management
- Addressing the issue of transport, particularly to properties own by the trust

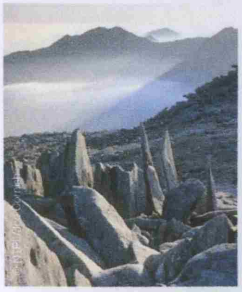


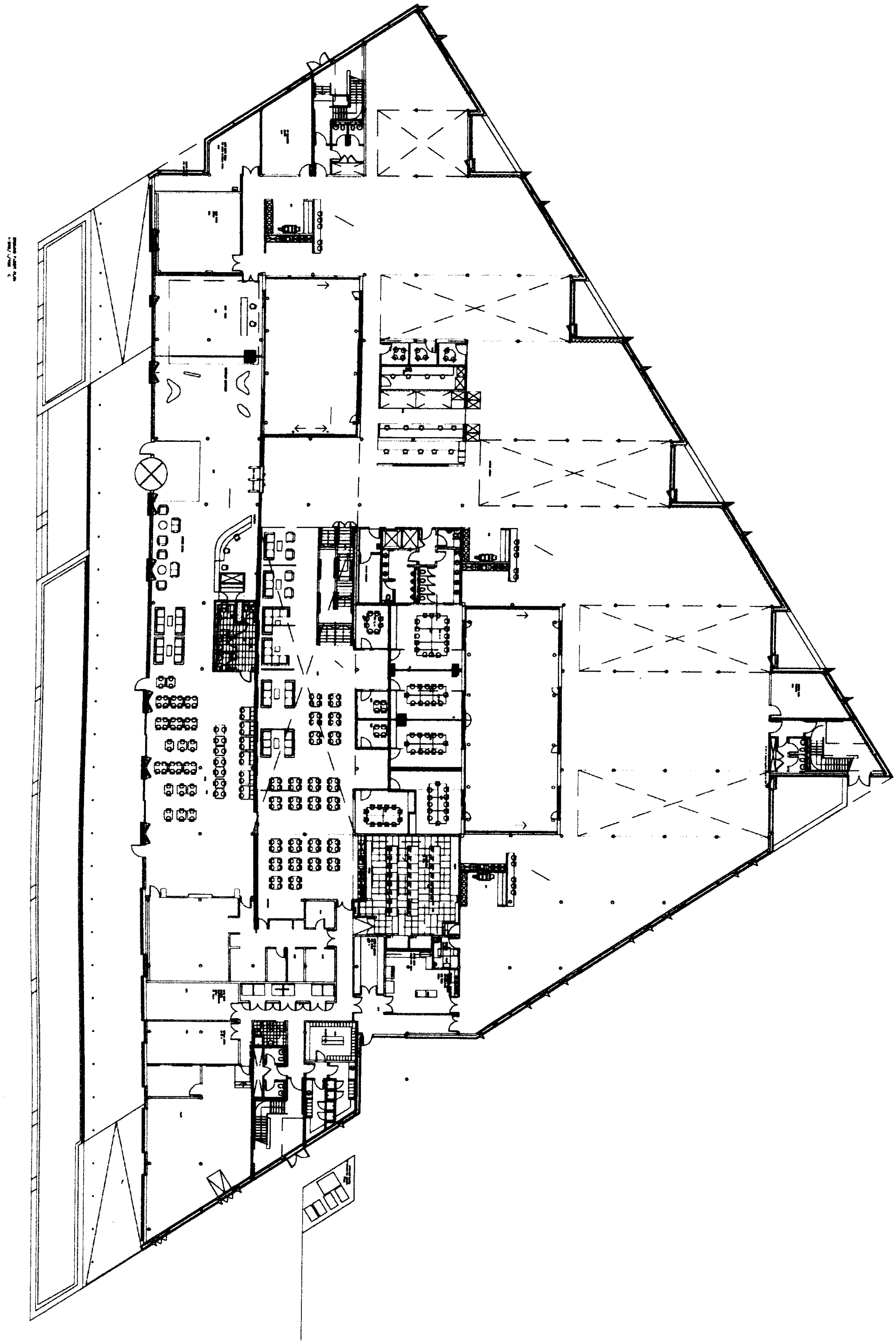
Figure (8.6):
Some of the projects that are run by the National Trust that promote their on going strategy to tackle crucial environmental issues: The photograph (left) is part of the EXPOSED Climate Change Exhibition touring the country in 2007 and 2008, highlighting the impact of climate change on places that are in the care of the National Trust. The Footprint Building, Windermere, Cumbria (middle) opened in summer 2007, and is a 'green' education centre. Built largely by volunteers, its construction materials include straw bales and recycled tyres. The National Trust also developed a number of car-free solution to travel in partnership with public transport operators like the ferry landing stage at Trelissick Garden on the Falestuary in Cornwall (right), *Source [36]*

It is therefore no surprise that the National Trust have pushed for their central office building to be an example that could reflect the organization's environmental policy and commitment to sustainability. During its early stages, the design brief indicated that the building "will be judged against the National Trust's comprehensive Sustainability Brief, and ultimately against the pervading interpretation of the subject, and developments in building technology" [23], a challenge that set high standards for the designers to achieve, including aiming at "innovative" benchmarks in key high profile areas and both "good and best practice" ones in others.

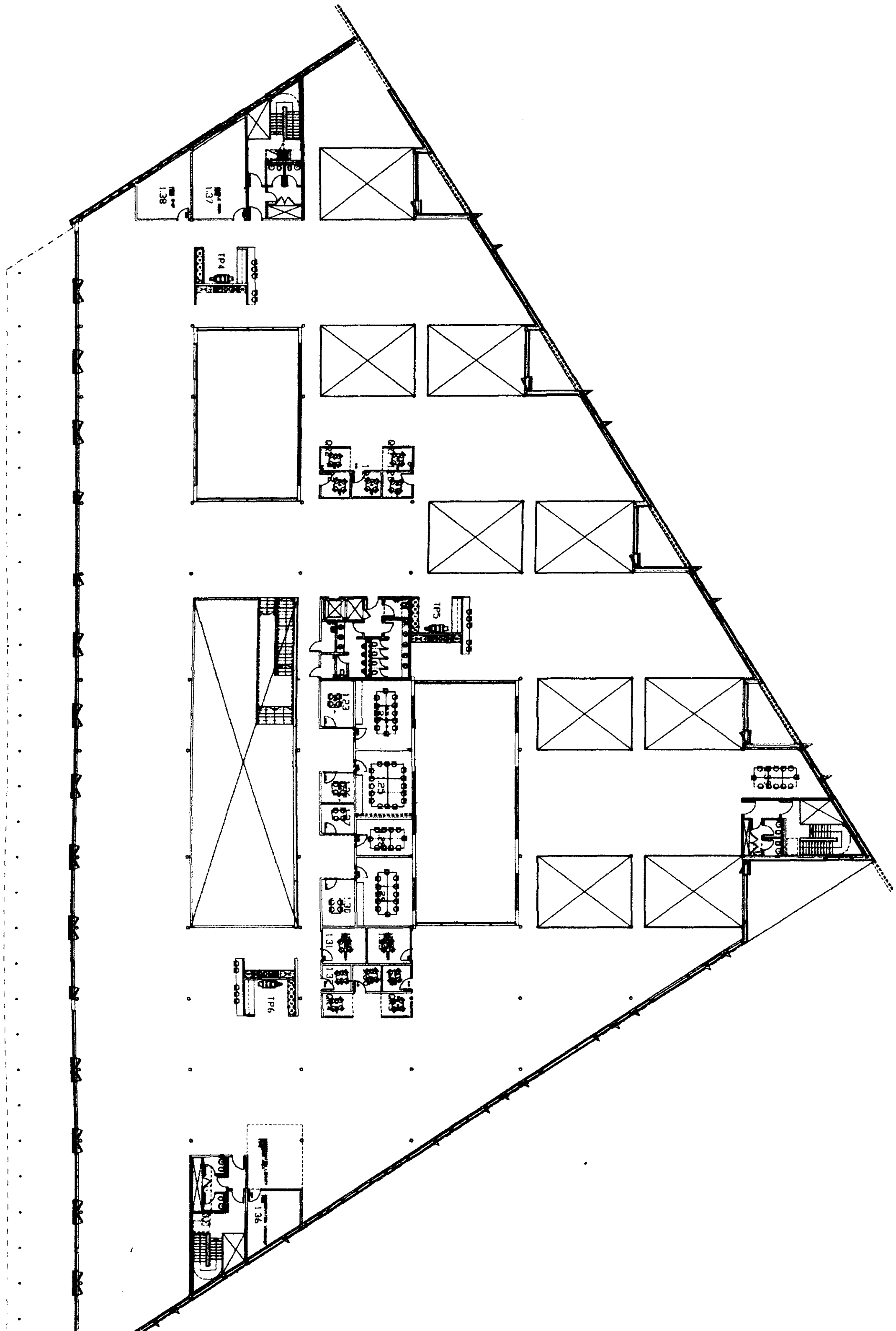
Furthermore, the building was to bring together staff from various locations into a single work environment that that should be "warm and welcoming" [23] to those who there as well as the public. Placing these requirements into the context of the site and its history presented designers with a challenge that, if successful, would redefine the way we interpret working environments both architecturally and environmentally.

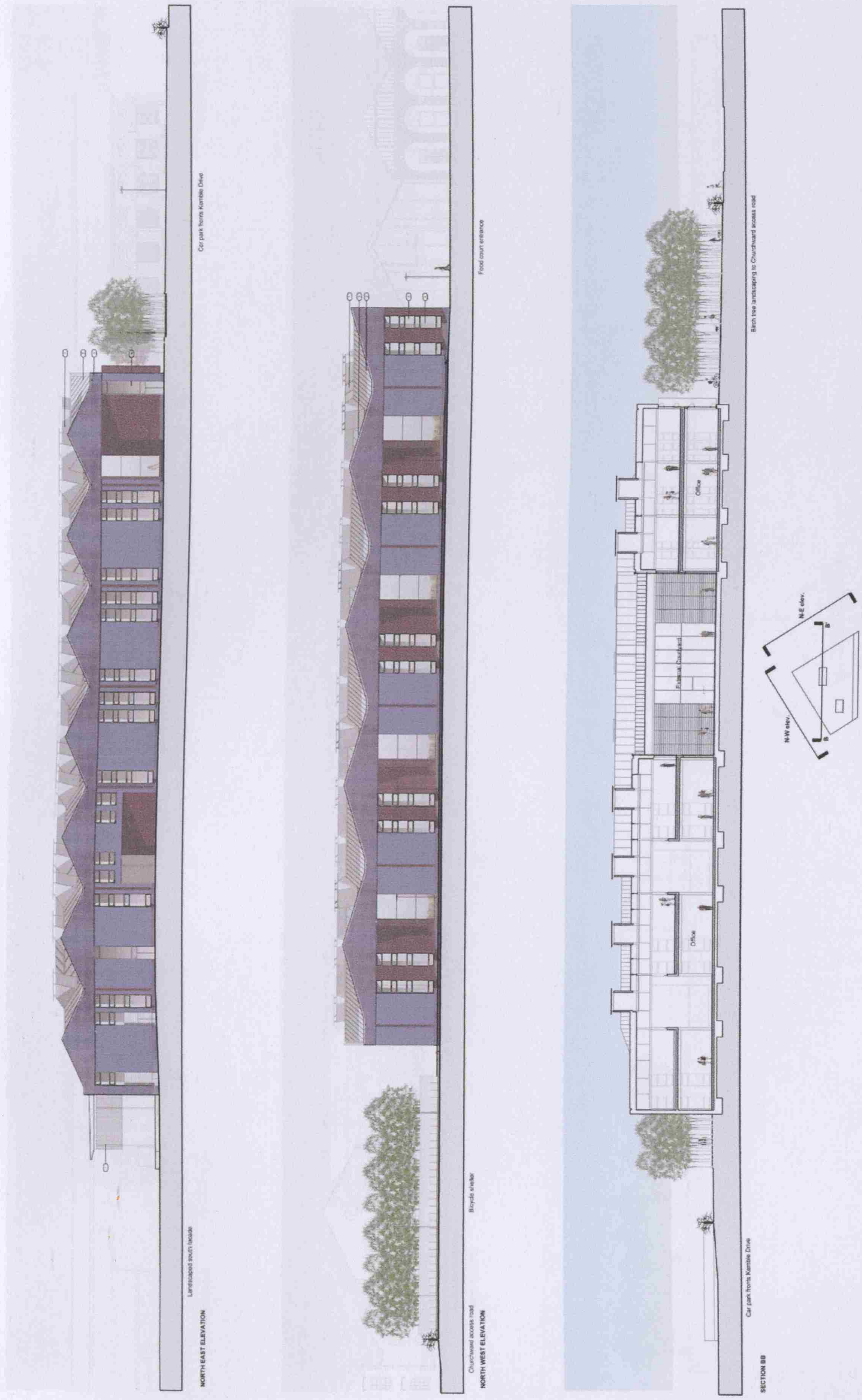
8.4 Drawings [23]

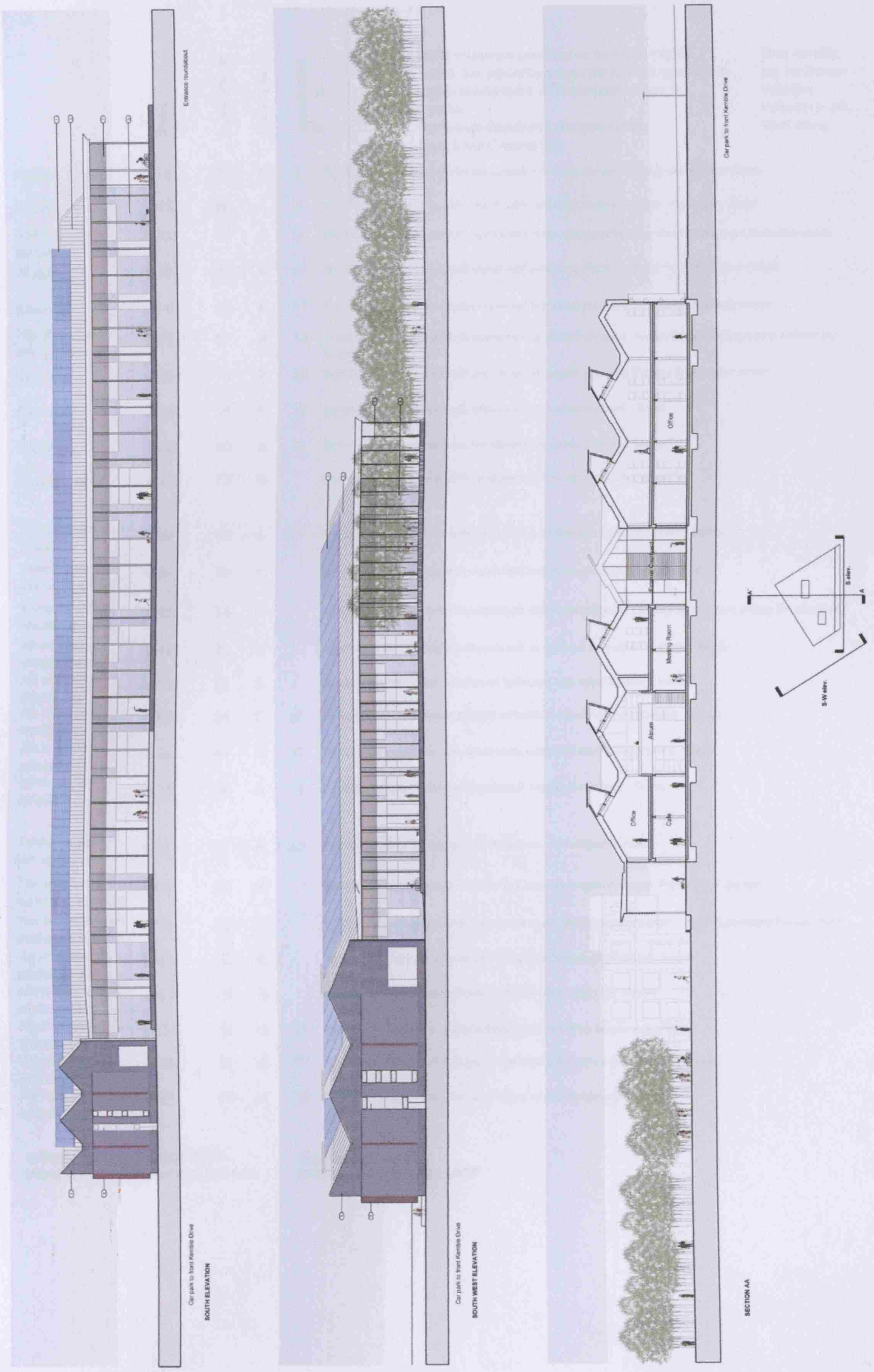
Ground Floor Plan



First Floor Plan




NORTH EAST ELEVATION
Landscaped south facade
NORTH WEST ELEVATION
Churchward access road
Bicycle shelter
SECTION BB
Birch tree landscaping to Churchward access road
N-E elev.
N-W elev.



8.5 Occupant Survey Results

High percentile scores are good scores for type A ('right-handed') scales; low percentile scores are good for type C ('left-handed' scales. Scores close to 50 are good for type B ('centred') scales.

Percentage dissatisfied are included for Type A and C scales only

Grey shading, e.g. for Design, indicates inclusion in the short rating

	Score	Percentile	Scale type	Dissatisfied %	
Design	**5.79**	85	A	7	Significantly higher than both benchmark and scale midpoint. Design satisfactory Green
Needs	**5.63**	80	A	6	Significantly higher than both benchmark and scale midpoint. Needs satisfactory Green
Space in the building	**5.34**	82	A	9	Significantly higher than both benchmark and scale midpoint. Space in the building satisfactory Green
Image	**5.86**	62	A	6	Significantly higher than both benchmark and scale midpoint. Image to visitors good Green
Cleaning	**5.06**	68	A	17	Significantly higher than both benchmark and scale midpoint. Cleaning satisfactory Green
Meeting room availability	**4.80**	57	A	14	Significantly higher than both benchmark and scale midpoint. Availability of meeting rooms satisfactory Green
Storage	**4.28**	71	A	35	Significantly higher than both benchmark and scale midpoint. Storage highly rated Green
Facilities	**5.56**	68	A	8	Significantly higher than both benchmark and scale midpoint. Green
Furniture	**5.60**	89	A	5	Significantly higher than both benchmark and scale midpoint. Green
Space at desk	**4.31**	77	B		Significantly higher than both benchmark and scale midpoint. Amber/Red
Temperature in winter	**4.33**	50	A	31	Significantly higher than scale midpoint but no different from benchmark. Amber
Temperature in winter: hot/cold	**4.90**	88	B		Significantly higher than both benchmark and scale midpoint. Too cold. Red
Temp in winter: stable/varies	**5.03**	88	B		Significantly higher than both benchmark and scale midpoint. Variable temperature during the day. Red
Air in winter: still/draughty	**3.95**	72	B		Significantly higher than benchmark and no different from scale midpoint. Green
Air in winter: dry/humid	**3.51**	83	B		Significantly higher than benchmark but lower than scale midpoint. Amber
Air in winter: fresh/stuffy	**4.00**	24	C	33	No significant difference from scale midpoint but lower than benchmark. Amber
Air in winter: odourless	**3.25**	44	C	17	Significantly lower than both benchmark lower limit and scale midpoint. Green
Air in winter: overall	**4.34**	59	A	31	Significantly higher than both benchmark and scale midpoint. Green
Temperature in summer	**4.13**	62	A	42	Significantly higher than benchmark but not scale midpoint. Amber
Temperature in summer: hot/cold	**3.86**	80	B		Significantly higher than benchmark but lower than scale midpoint. Possibly hot. Amber
Temp in summer: stable/varies	**4.74**	78	B		Significantly higher than both benchmark and scale midpoint. Variable temperature during the day. Red
Air in summer: still/draughty	**3.47**	72	B		Significantly higher than benchmark but lower than scale midpoint. Amber
Air in summer: dry/humid	**3.63**	48	B		No different from benchmark but lower than scale midpoint. Amber
Air in summer: fresh/stuffy	**4.27**	33	C	41	Significantly higher than scale midpoint but lower than benchmark. Amber
Air in summer: odourless	**3.23**	30	C	17	Significantly lower than both benchmark lower limit and scale midpoint. Green
Air in summer: overall	**4.21**	68	A	35	Significantly higher than both benchmark and scale midpoint. Green

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	Score	Percentile	Scale type	Dissatisfied %		
Noise overall	4.44	58	A	29	Significantly higher than scale midpoint but no different from benchmark. Amber	
Noise from colleagues	4.42	59	B		Significantly higher than both benchmark and scale midpoint. Possibly too much noise from colleagues. Red	
Noise from other people	4.72	85	B		Significantly higher than both benchmark and scale midpoint. Too much noise from other people. Red	
Other noise from inside	4.41	83	B		Significantly higher than both benchmark and scale midpoint. Too much noise from inside. Red	
Noise from outside	3.72	46	B		Significantly lower than both benchmark and scale midpoint. Red	
Noise: unwanted interruptions	3.76	28	C	39	Significantly lower than both benchmark and scale midpoint. Green	
Lighting overall	4.78	60	A	28	Significantly higher than both benchmark and scale midpoint. Lighting satisfactory. Green	
Natural light	4.05	63	B		Significantly higher than benchmark but not scale midpoint. Green	
Glare from sun and sky	3.02	14	C	14	Significantly lower than both benchmark and scale midpoint. Green	
Artificial light	3.95	29	B		No different from scale midpoint but significantly lower than benchmark. Green	
Glare from lights	3.19	14	C	16	Significantly lower than both benchmark lower limit and scale midpoint. Green	
Comfort overall	5.23	82	A	15	Significantly higher than both benchmark and scale midpoint. Green	
Perceived productivity	1.00	62	A	37	No different from either benchmark or scale midpoint. Amber	
Health	4.19	93	A	26	Significantly higher than both benchmark and scale mid point. Green	
Safety	6.22			1	New variable introduced 2007 No benchmarks available yet	
Perceived control						Per cent rating as important
Heating	1.94	48	A	81	Significantly lower than both benchmark lower limit and scale midpoint. Little or no control over heating Red	27
Cooling	2.52	58	A	71	No different from benchmark but lower than scale midpoint. Amber	26
Ventilation	3.38	58	A	52	Significantly higher than benchmark but lower than scale midpoint. Amber	36
Lighting	2.04	18	A	80	Significantly lower than both benchmark and scale midpoint. Little or no control over lighting Red	16
Noise	1.70	23	A	87	Significantly lower than both benchmark lower limit and scale midpoint. Little or no control over noise Red	20

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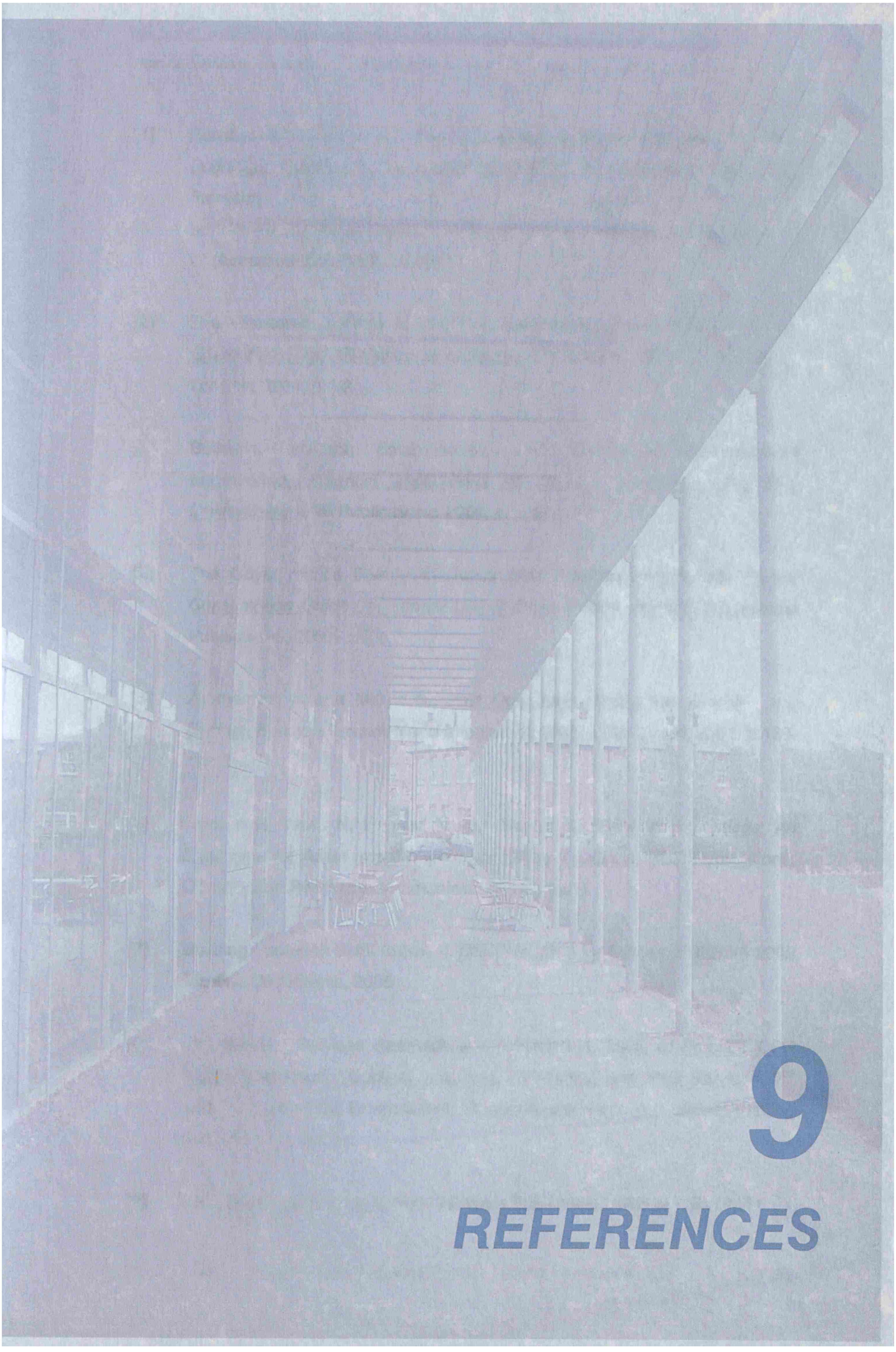
BUS UK benchmarks 2007

8.6 List of Figures

8.7 List of Tables



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